

# **1994 URSI Commission-F Microwave Specialist Symposium**

**on  
Microwave Remote Sensing  
of the Earth, Oceans, Ice,  
and Atmosphere**

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**Lawrence, Kansas, USA  
May 18-20, 1994**

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1994 URSI Commission-F  
Microwave Specialist Symposium  
on  
Microwave Remote Sensing  
of the Earth, Oceans, Ice, and Atmosphere

## Program and Abstracts

Lawrence, Kansas, USA  
May 18-20, 1994

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## Welcome

On behalf of the Organizing Committee it is our privilege to welcome you to the 1994 URSI Commission-F Microwave Specialist Symposium on Microwave Remote Sensing of the Earth, Oceans, Ice, and Atmosphere. The symposium is being held at the Holiday Inn Holidome in Lawrence, Kansas, which is only a few minutes from the beautiful campus of The University of Kansas. We are holding it in Lawrence partly to honor the university retirement of Prof. Richard K. Moore

The symposium's objective is to provide a forum for exchanging information on the latest developments in microwave remote sensing. The decade of the 1990s promises to be an exciting era for microwave remote sensing. We feel that an excellent technical program has been assembled, featuring many aspects of microwave remote sensing including a special session on ERS-1.

A total of 61 papers will be presented at the symposium in two parallel sessions. Half of the papers are from outside the United States. Moving from one session to another will be easy, since the meetings are being held in adjacent rooms. We hope that you will have ample opportunity to visit with old friends and make new ones while you are here.

Partial support of the symposium has been provided by URSI Commission F, the Office of Naval Research (ONR) of The United States, the National Aeronautics and Space Administration (NASA) of The United States, and The University of Kansas. The University of Kansas generously gave funds partially to support four URSI Young Scientists' attendance at this symposium—two from Russia, one from Norway and one from Colorado in the USA.

Lawrence is a college town. It is only a short distance from the large metropolitan area of Kansas City. A few outstanding attractions in Lawrence include our museums, parks, and exclusive shopping areas. Once again, we welcome you!

S. Prasad Gogineni, General Chairman  
Evert Attema, Co-Chairman  
Kenneth C. Jezek, Technical Program Chairman

## **Sponsors**

We gratefully acknowledge the contributions and support of the following organizations

**URSI Commission F  
Office of Naval Research (ONR)  
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Radar Systems and Remote Sensing Laboratory, The  
University of Kansas Center for Research, Inc.**

**1994 URSI Commission-F Microwave Specialist Symposium on Microwave Remote Sensing of the Earth, Oceans, Ice, and Atmosphere**

**May 18 to 20, 1994  
Lawrence, Kansas, USA**

**Program**

***Tuesday, May 17***

- 4:00-8:00 p.m. **Registration**  
Convention Center Lobby, Lawrence Holiday Inn/Holidome
- 6:00-10:00 p.m. **No-host (cash) Bar**  
Chancellor's Suite, Lawrence Holiday Inn/Holidome

***Wednesday, May 18***

**Posters**

Posters of the following papers will remain in the Convention Center Lobby throughout the Symposium.

"An investigation into the utility of high-resolution plane-wave scatterometer measurements for remote sensing of vegetation"

L. Lockhart, The University of Kansas, Lawrence KS

"Neural network based classification of SAR scenes using spectral information: An empirical study"

T. S. Chuah & S. Chakrabarti, The University of Kansas, Lawrence KS

"Preliminary results from the winter Weddell Sea ice classifications of ERS-1 SAR imagery using neural network"

A. R. Hosseinmostafa, S. Chakrabarti & M. R. Drinkwater, The University of Kansas, Lawrence KS, & Jet Propulsion Laboratory, Pasadena CA

"A new application of the compact range antenna concept to geophysical research"

K. C. Jezek, S. P. Gogineni, L. Peters, J. Young, S. Beaven, E. Nassar & I. Zabel, The Ohio State University, Columbus OH, & The University of Kansas, Lawrence KS

- 7:00-8:40 a.m. **Registration and Morning Refreshments**  
Convention Center Lobby, Lawrence Holiday Inn/Holidome

- 8:40-9:00 a.m. **Welcoming Remarks**  
Brazilian C and D  
Edward L. Meyen, Executive Vice Chancellor, The University of Kansas  
S. Prasad Gogineni, General Chairman, The University of Kansas, Lawrence KS  
Kenneth C. Jezek, Technical Chairman, The Ohio State University, Columbus OH

- 9:00-10:00 a.m. **Keynote Address**  
Brazilian C and D  
"History of Microwave Remote Sensing"  
Kiyo Tomiyasu, General Electric, Philadelphia PA

- 10:00-10:30 a.m. **Break** *Wednesday, May 18, continued*
- 10:30-12:00 a.m. **Session A—Oceans**  
 Brazilian C  
 Chairman: W. J. Pierson, Jr., City College, New York NY  
 Co-chairman: S. Haimov, The University of Kansas, Lawrence KS
- 10:30-11:00 a.m. "Implications of non-linear wave properties on the theory, design and interpretation of in situ and remotely sensed wind generated ocean waves and swell"  
 W. J. Pierson, Jr., City College, New York NY
- 11:00-11:30 a.m. "Measurements of surface wind on the ocean using an airborne radar looking at small incidence angles"  
 D. Hauser, Centre Universitaire, Velizy, France
- 11:30-12:00 a.m. "Ocean surface observations with a Focused Phased Array Imaging Radar"  
 S. J. Frasier & R. E. McIntosh, University of Massachusetts, Amherst MA
- 10:30-12:00 a.m. **Session B—Ice**  
 Brazilian D  
 Chairman: M. Hallikainen, Helsinki University of Technology  
 Co-chairman: J. Bredow, The University of Texas, Arlington TX
- 10:30-11:00 a.m. "Use of active-passive microwave remote sensing methods of ice cover from satellites for navigation support in the Arctic"  
 V. Yu. Alexandrov, A. V. Bushuev, V. D. Grishchenko, V. S. Loshchilov & P. A. Nikitin, Arctic and Antarctic Research Institute, St. Petersburg, Russia
- 11:00-11:30 a.m. "Changes in the surface properties of the Greenland ice sheet from an analysis of SEASAT and GEOSAT altimeter data"  
 C. H. Davis, University of Missouri at Kansas City, Kansas City MO
- 11:30-12:00 a.m. "C-band emission from stratified Antarctic firn: comparing models with measurements"  
 R. West, D. P. Winebrenner, L. Tsang & H. Rott, University of Washington, Seattle WA, & Leopold-Franzens-Universitaet, Innsbruck, Austria
- 12:00-1:30 p.m. **Lunch** (on your own or pre-paid in Brazilian A & B)
- 1:30-5:00 p.m. **Session A—Oceans (continued)**  
 Brazilian C  
 Chairman: W. J. Pierson, Jr., City College, New York NY  
 Co-chairman: S. Haimov, The University of Kansas, Lawrence KS
- 1:30-2:00 p.m. "Brewster angle effects on the microwave radar sea echo at low grazing angles"  
 D. B. Trizna, Naval Research Laboratory, Washington DC
- 2:00-2:30 p.m. "Comparison of two models for radar scattering from rain perturbed water surfaces"  
 P. W. Sobieski, V. Collot & L. F. Blivens, Universite Catholique de Louvain, Louvain-la-Neuve, Belgium, & NASA, Wallops Island VA
- 2:30-3:00 p.m. "About possibility oil-products discovering on the water surface by two-frequency method at the mm-wave band"  
 N. V. Ruzhentsev, V. P. Churilov & Yu. A. Kuzmenko, Institute of RadioAstronomy, Kharkov, Ukraine

- 3:00-3:30 p.m. **Break** *Wednesday, May 18, continued*
- 3:30-4:00 p.m. "Measurement of ocean wave properties using a vector slope gauge: An error analysis"  
C. Evans, S. Haimov & R. K. Moore, The University of Kansas, Lawrence KS
- 4:00-4:30 p.m. "Model function development and testing of models for radar backscattering from the sea surface"  
P. Snoeij, E. van Halsema, H. A. M. Janssen, J. Vogelzang, P. A. E. M. Janssen, W. A. Oost & C. J. Calkoen, Delft University of Technology, Delft, The Netherlands, and other organizations
- 4:30-5:00 p.m. "An analysis of the theoretical,  $K_p$ , and sample values of the normalized standard deviation,  $K_p(S)$ , for the active microwave instrument (AMI) on earth resources satellite-1 (ERS-1)"  
W. B. Sylvester & W. J. Pierson, Jr., City College, New York NY
- 1:30-5:00 p.m. **Session B—Ice (continued)**  
Brazilian D  
Chairman: M Hallikainen, Helsinki University of Technology  
Co-chairman: J. Bredow, The University of Texas, Arlington
- 1:30-2:00 p.m. "A dynamic local thresholding technique for distinguishing sea ice thicknesses in SAR data"  
D. Haverkamp, L. K. Soh & C. Tsatsoulis, The University of Kansas, Lawrence KS
- 2:00-2:30 p.m. "Using ground truth to understand the effects of sub-surface features on radar altimeter return waveforms from the percolation zone in Greenland"  
E. J. Ferraro & C. T. Swift, University of Massachusetts, Amherst MA
- 2:30-3:00 p.m. "Microwave backscatter from laboratory-grown saline ice"  
I. H. H. Zabel, K. C. Jezek, S. P. Gogineni, R. Hosseinmostafa & G. L. Lockhart, The Ohio State University, Columbus OH & The University of Kansas, Lawrence KS
- 3:00-3:30 p.m. **Break**
- 3:30-4:00 p.m. "Observations of seasonal and interannual sea ice variations in the Barents and Kara seas through the use of SMMR and SSM/I data" (**URSI Young Scientist Award**)  
E. Bjørge & S. Sandven, Nansen Environmental and Remote Sensing Center, Bergen, Norway
- 4:00-4:30 p.m. "Combined use of radar and microwave radiometer in remote sensing of snow"  
M. Hallikainen, J. Koskinen, L. Kurvonen & V. Jääskeläinen, Helsinki University of Technology
- 4:30-5:00 p.m. "Structure dependence model of wet snow microwave emissivity for remote sensing" (**URSI Young Scientist Award**)  
D. A. Boyarskii, Space Research Institute, Moscow, Russia
- 5:00-on p.m. **Dinner and Evening (on your own)**

*Thursday, May 19*

- 7:00 a.m. **Registration**  
Convention Center Lobby
- 7:00-8:30 a.m. **Morning Refreshments**  
Convention Center Lobby
- 8:30-12:00 a.m. **Session A—Oceans and Ice**  
Brazilian C  
Chairman: C. Swift, University of Massachusetts, Amherst MA  
Co-chairman: K. St. Germain, University of Nebraska, Lincoln NE
- 8:30-9:00 a.m. "Effects of multi-scale roughness on surface scattering"  
A. K. Fung, The University of Texas, Arlington TX
- 9:00-9:30 a.m. "Polarimetric measurements of sea surface brightness temperatures using an aircraft K-band radiometer"  
S. H. Yueh, W. J. Wilson, S. V. Nghiem, F. K. Li & W. B. Ricketts, Jet Propulsion Laboratory, Pasadena CA
- 9:30-10:00 a.m. "Estimation of surface wind speed in hurricanes using airborne microwave spectral radiometer measurements"  
K. M. St. Germain, P. G. Black & C. T. Swift, University of Nebraska, Lincoln NE, NOAA, Miami FL & University of Massachusetts, Amherst MA
- 10:00-10:30 a.m. **Break**
- 10:30-11:00 a.m. "Model of complex dielectric constant of wet snow in the 1-50 GHz range" (URSI Young Scientist Award)  
V. V. Tikhonov & D. A. Boyarskii, Space Research Institute, Moscow, Russia
- 11:00-11:30 a.m. "Polar ice temperature estimation from satellite borne passive microwave measurements"  
K. M. St. Germain, University of Nebraska, Lincoln NE
- 11:30-12:00 a.m. "VAGSAT: A proposal for a small satellite mission for the measurement ocean wave spectra with a real-aperture radar"  
D. Hauser, Centre Universitaire, Velizy, France
- 8:30-12:00 a.m. **Session B—ERS-1**  
Brazilian D  
Chairman: Evert Attema, ESA/ESTEC, Noordwijk, The Netherlands  
Co-chairman: M. Drinkwater, Jet Propulsion Laboratory, Pasadena CA
- 8:30-9:00 a.m. "On the use of ERS-1 SAR data for the retrieval of bare soil geo-physical parameters" (Invited Paper)  
M. Borgeaud, J. Noll & A. Bellini, European Space Agency, ESTEC-XEP, Noordwijk, The Netherlands
- 9:00-9:30 a.m. "Improving interpretations of ERS-1 SAR images by combination with coincident AVHRR images" (Invited Paper)  
J. A. Johannessen, O. M. Johannessen, P. W. Vachon & R. A. Shuchman, European Space Agency, ESTEC, Noordwijk, The Netherlands, and other organizations
- 9:30-10:00 a.m. "Mesoscale atmospheric phenomena studied by ERS-1 SAR" (Invited Paper)  
W. Alpers, University of Hamburg, Hamburg, Germany

- 10:00-10:30 a.m. **Break** *Thursday, May 19, continued*
- 10:30-11:00 a.m. "Assessment of ERS-1 SAR data for the retrieval of soil moisture" (Invited Paper)  
T. le Toan, J. C. Souyris & N. Boudier, Universite Paul Sabatier, Toulouse, France
- 11:00-11:30 a.m. "Calibration of the active microwave instrument onboard ERS-1" (Invited Paper)  
P. Hogeboom, J. S. Groot, A. C. v. d. Broek, Y. L. Desnos, M. Laur & J. Kleijweg, TNO-FEL, The Hague, The Netherlands, and other organizations
- 11:30-12:00 a.m. "Observations of temporal changes in crop backscatter using ERS-1 SAR" (Invited Paper)  
G. E. Keyte, P. J. Bird, R. L. Golding & M. Wooding, DRA Farnborough, Hampshire, England, & RSAC, England
- 12:00-1:30 p.m. **Lunch** (on your own or pre-paid in Brazilian A & B)
- 1:30-5:00 p.m. **Session A—Atmosphere**  
Brazilian C  
Chairman: R. McIntosh, University of Massachusetts, Amherst MA  
Co-chairman: D. Kieu, GenCorp Aerojet, Azusa CA
- 1:30-2:00 p.m. "Comparison of experimental measured and size calculated to vertical profiles atmosphere absorption in 3-mm wave band"  
N. V. Ruzhentsev & V. P. Churilov, Institute of Radioastronomy, Kharkov, Ukraine
- 2:00-2:30 p.m. "Estimation of the rain signal in presence of large surface clutter"  
A. Ahamad & R. K. Moore, The University of Kansas, Lawrence KS
- 2:30-3:00 p.m. "A 75-110 GHz radar/spectrometer for pollution monitoring"  
J. Bredow & S. Nadimi, The University of Texas, Arlington TX
- 3:00-3:30 p.m. **Break**
- 3:30-4:00 p.m. "Polarimetric dual-frequency millimeter-wavelength observations of stratus clouds and rain"  
S. M. Sekelsky, J. Firda & R. E. McIntosh, University of Massachusetts, Amherst MA
- 4:00-4:30 p.m. "Preliminary analysis of the performance of the special sensor microwave water vapor profiler (SSM/T-2) if some channel(s) become(s) inoperative"  
D. C. Kieu, A. Stogryn & B. Kreiss, GenCorp Aerojet, Azusa CA
- 4:30-5:00 p.m. "Seasonal-weather investigations earth cover radiation in 3-mm wave band"  
N. V. Ruzhentsev & V. P. Churilov, Institute of Radioastronomy, Kharkov, Ukraine
- 1:30-5:00 p.m. **Session B—ERS-1 (continued)**  
Brazilian D  
Chairman: Evert Attema, ESA/ESTEC, Noordwijk, The Netherlands  
Co-chairman: M. Drinkwater, Jet Propulsion Laboratory, Pasadena CA
- 1:30-2:00 p.m. "Crop discrimination using multi-temporal ERS-1 SAR data" (Invited Paper)  
M. G. Wooding, A. D. Zmuda & A. J. Batts, Remote Sensing Applications Consultants, Hampshire, United Kingdom

*Thursday, May 19, continued*

- 2:00-2:30 p.m. "Use of statistical analysis for ice-ocean discrimination"  
R. Garelo & B. Chapron, Ecole Nationale Supérieure des Télécommunications, Brest, France, & Département Oceanographie Spatiale, Plouzané, France
- 2:30-3:00 p.m. "Statistical analysis of the relation between SAR and RAR ocean wave images"  
B. Chapron & R. Garelo, Département Oceanographie Spatiale, Plouzané, France, & Ecole Nationale Supérieure des Télécommunications, Brest, France
- 3:00-3:30 p.m. **Break**
- 3:30-4:00 p.m. "Comparison of shipborne radar measurements and ERS-1 SAR images of sea ice"  
S. G. Beaven, The University of Kansas, Lawrence KS
- 4:00-4:30 p.m. "ERS-1 investigations of southern ocean sea ice geophysics using scatterometer and SAR images"  
M. R. Drinkwater, D. G. Long & D. S. Early, Jet Propulsion Laboratory, Pasadena CA, & Brigham Young University, Provo UT
- 4:30-5:00 p.m. "Remote sensing of moisture patterns around lakes using combined ERS-1 and JERS-1 radar backscatter data"  
R. M. Narayanan, M. S. Hegde & D. C. Rundquist, University of Nebraska, Lincoln NE
- 6:00-6:30 p.m. **Reception** (for all conference participants, in Regency D)
- 6:30 on **Banquet** (pre-paid, in Brazilian A & B)

**Friday, May 20**

7:30-8:00 a.m. **Morning Refreshments**  
Convention Center Lobby

8:00-12:30 a.m. **Session A—Vegetation/Soil**  
Brazilian C

Chairman: A. Fung, The University of Texas, Arlington TX

Co-chairman: A. J. Sieber, Joint Research Centre, Ispra, Italy

8:00-8:30 a.m. "High-resolution imaging of subsurface targets using a ground-penetrating radar"

P. Chaturvedi & R. G. Plumb, The University of Kansas, Lawrence KS

8:30-9:00 a.m. "Theoretical model for remote sensing of vegetation"

C. C. Hsu, W. C. Au, J. A. Kong & L. Tsang, Massachusetts Institute of Technology, Cambridge MA, & University of Washington, Seattle WA

9:00-9:30 a.m. "Earth surfaces backscattering characteristics in 2-mm and 3-mm wave band"

N. V. Ruzhentsev & V. P. Churilov, Institute of Radioastronomy, Kharkov, Ukraine

9:30-10:00 a.m. "First results from the European Microwave Signature Laboratory"

A. J. Sieber, Joint Research Centre, Ispra, Italy

10:00-10:30 a.m. **Break**

10:30-11:00 a.m. "The use of the radar equation for truck-based scatterometer measurements from vegetation"

N. Khadr & R. H. Lang, George Washington University, Washington DC

11:00-11:30 a.m. "Modelisation and measurement of radar backscattering over agricultural bare soils"

O. Taconet, L. Rakotoarivony, M. Benallegue & D. Vidal-Madjar, CETP/CNRS, Velizy, France

11:30-12:00 a.m. "Gas sensing radar"

W. P. Waite, V. H. Kaupp, H. C. MacDonald, J. Sandy & G. Hawkins, Arkansas Research Consultants, Fayetteville AR

12:00-12:30 p.m. "A new application of the compact range antenna concept to geophysical research"

K. Jezek, S. P. Gogineni, L. Peters, J. Young, S. Beaven, E. Nassar & I. Zabel, The Ohio State University, Columbus OH, & The University of Kansas, Lawrence KS

8:00-12:30 a.m. **Session B—Systems/Calibration**  
Brazilian D

Chairman: P. Snoeij, Delft University of Technology, Delft, The Netherlands

Co-chairman: I. Zabel, The Ohio State University, Columbus OH

8:00-8:30 a.m. "Theory and development of the active transponder for altimetry calibration (ATAC)" (URSI Young Scientist Award)

M. B. Mathews, P. F. MacDoran & D. B. Shaffer, University of Colorado, Boulder CO

8:30-9:00 a.m. "A polarization selective corner reflector for polarimetric SAR calibration"

M. Fujita & T. Masuda, Communication Research Laboratory, Tokyo, Japan

*Friday, May 20, continued*

- 9:00-9:30 a.m. "The JPL aircraft topographic synthetic aperture radar (TOPSAR) program"  
T. W. Thompson, H. A. Zebker, R. E. Carande, P. A. Rosen, S. N. Madsen,  
S. Hensley, J. J. van Zyl & T. W. Miller, Jet Propulsion Laboratory, Pasadena  
CA
- 9:30-10:00 a.m. "Scattering prediction and measurement of thin wire arrays with random  
heights"  
P. Snoeij & P. J. F. Swart, Delft University of Technology, Delft, The  
Netherlands
- 10:00-10:30 a.m. **Break**
- 10:30-11:00 a.m. "Analysis of the 2-d response pattern of the EMSL antennae and applicability  
of a polarimetric calibration"  
A. J. Sieber, G. Nesti, H. B. Mortensen, E. Ohlmer & D. Tarchi, JRC, Ispra,  
Italy, & Fondazione Scienza per l'Ambiente, Firenze, Italy
- 11:00-11:30 a.m. "Passive microwave remote sensing with thinned array radiometers"  
C. T. Swift, D. M. LeVine, T. J. Jackson, A. Griffis, M. Kao & P. Gaiser,  
University of Massachusetts, Amherst MA, and other organizations
- 11:30-12:00 a.m. "Current status of the PHARUS (polarimetric phased array airborne C-band  
SAR) project"  
P. Snoeij, P. Hoogeboom, P. J. Koomen, B. C. B. Vermeulen, M. Paquay, and  
H. Pouwels, Delft University of Technology, Delft, The Netherlands, and other  
organizations
- 12:00-12:30 p.m. "Opportunities for combined GPS orbit determination and spread spectrum  
altimetry"  
P. F. MacDoran & M. B. Mathews, University of Colorado, Boulder CO
- 12:30 p.m. **Conference adjourns**

**After Lunch      Tour of Radar Systems and Remote Sensing Laboratory**

If you want to tour our laboratory, please see Ms. Donnis Graham to make  
arrangements and sign up.

## **Abstracts**

## **Oceans**

IMPLICATIONS OF NON-LINEAR WAVE PROPERTIES ON THE THEORY, DESIGN  
AND INTERPRETATION OF IN-SITU AND REMOTELY SENSED  
WIND GENERATED OCEAN WAVES AND SWELL

Willard J. Pierson Jr.

Remote Sensing Laboratory. The City College of New York, New York, N.Y.

In-situ wave measuring systems and remote sensing systems on earth-orbiting spacecraft are often designed using a linear wave model and the raw data are usually analyzed and interpreted by linear theory. The equations that describe these waves are non-linear, and certain types of in-situ measurements clearly demonstrate non-linear wave properties. Non-linear wave properties are interpreted in terms of some recent theoretical studies, and the need to re-analyze the design of these systems and re-interpret the raw data is described. Some suggestions on how this might be accomplished are given.

## **MEASUREMENTS OF SURFACE WIND ON THE OCEAN USING AN AIRBORNE RADAR LOOKING AT SMALL INCIDENCE ANGLES**

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The results to be presented deal with measurements performed with the french airborne radar RESSAC. This system was initially designed for the measurement of the directional spectra of large waves (50 to 400 m in wavelength): looking angles between 7 and 21 ° with respect to nadir, rotating antenna to scan over 360° in azimuth. In this presentation, we will show that in addition to the directional spectra provided by RESSAC, an information on the surface wind can also be obtained. The method is based upon the analysis of the fall-off of the normalized radar cross-section  $\sigma_0$  in the [7, 21°] range of incidence angles  $\theta$  (with respect to nadir), both as an azimuthally-averaged quantity and as a function of the azimuth angle. We will show that the mean fall-off is related to the wind speed measured by buoys or derived from observations of a classical wind scatterometer (the german airborne RACS) looking at a greater incidence angle ( $\approx 40^\circ$ ). Moreover, we will show that by using an harmonic analysis applied on the RESSAC observations of the fall-off of  $\sigma_0$  as a function of the azimuth angle  $\phi$ , the surface wind direction is retrieved in good agreement with that given by the wind scatterometer RACS, and by the buoy measurements. Analysis of the amplitude of the harmonic behaviour of the fall-off will also be presented, with comparisons with the crosswind/up-downwind modulation measurement by the wind scatterometer RACS. Implications of these results for the combined measurement of wind and waves by using a single device will be discussed.

## **Ocean Surface Observations with a FOCused Phased Array Imaging Radar**

Stephen J. Frasier and Robert E. McIntosh

Microwave Remote Sensing Laboratory  
University of Massachusetts  
Amherst, MA 01003

A FOCused Phased Array Imaging Radar (FOPAIR) has been developed for fine-scale ocean measurement applications. It employs a fast sequentially sampled linear array combined with software-based beamforming techniques to provide high-resolution, high-speed X-Band imagery of the moving ocean surface. Typical complex radar images are acquired within 1.2 milliseconds, or about an order of magnitude faster than the decorrelation time of the surface. They span an area of up to 6400 square meters with spatial resolution of approximately one square meter. Imaging rates of up to 180 complex images per second also permits rapid accumulation of backscatter statistics.

During July of 1993 FOPAIR was deployed on the pier at the Scripps Institute of Oceanography where preliminary ocean surface measurements at near-grazing angles were performed. Sample images of backscattered power and radial velocity (mean doppler shift) show both long swell and shorter wind-generated wave features. Intermittent bright, high-velocity scattering features indicative of possible small-scale wave breaking are noted. The bivariate pdf of measured power and velocity also illustrates the correlation between the highest measured powers and velocities.

**BREWSTER ANGLE EFFECTS  
ON THE MICROWAVE RADAR SEA ECHO AT LOW GRAZING ANGLES**

Dennis B. Trizna  
Propagation & Scattering Staff, Radar Division  
Naval Research Laboratory  
Washington, D.C. 20375-5000

**ABSTRACT**

Brewster angle damping effects are considered by studying linear polarization differences in the illumination of discrete ocean surface feature sea scattering sources at microwave frequencies. In order to isolate this propagation effect from target scattering effects, we consider the electromagnetic boundary conditions for the illumination of moderate height scattering sources that stand above the mean sea surface, such as steep wave crests or bores. The effects of forward scattered energy in the illumination of slightly elevated features are different from the illumination of the slightly rough surface that satisfies the first order perturbation theory, in that strong interference patterns may now occur. We consider horizontal and vertical polarizations at low grazing angles, for six radar bands (L, S, C, X, Ka, Ku), for a perfectly conducting surface, fresh water and sea water. Brewster angle effects are significant at VV for the latter two cases relative to the perfect conductor, but not for HH. In general we find that for discrete scatterers a centimeter and higher, at X-band the HH illumination is enhanced while that for VV is damped. This behavior scales with radar wavelength, so that higher wave features are required to produce sea spike echoes for radar frequencies far below X-band. As an application of these results, we also examine the influence of illumination pattern variations for two-way propagation plus scattering, for a scatterer located at various points on a long sinusoidal gravity wave. These results indicate that the dynamic range of the HH echo is significantly larger than for VV. The largest illumination gain difference is 12 dB higher at low grazing for HH than for VV, and becomes equal at roughly 45° and higher. These results can begin to explain recent field experiments where scatter from short steep waves in a current rip area was found to be larger for HH than for VV for grazing angles less than about 5°.

## Comparison of two models for radar scattering from rain perturbed water-surfaces

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Scatterometric and altimetric measurements of the ocean surface are perturbed by precipitation, so normally these data are discarded in order to avoid biases on retrieved wind fields. However, some of the inversion procedures for rain, in particular those that retrieve vertical profiles from spaceborne radar data, require input of the surface-return for computations. Unfortunately backscattering from the sea-surface under rainy conditions has not been extensively studied, so there are still some uncertainties regarding specification of operational conditions for various combinations of wind and rain.

The starting point of the study presented here is a model by Wetzel (*Radio Sc.* 1990, 25 (6), 1183-1197) for high incidence angles that are near grazing. This model is based on X-band measurements in a laboratory using individual drops. The data show that the major surface feature contributing to the backscattering is the stalk generated just after a raindrop impacts the water surface. We present a review of the assumptions underlying the electromagnetic model for the backscattering by stalks. The formulation is then extended and applied to the calculation of radar backscattering cross-sections versus rain intensity, as characterised by a Marshall-Palmer drop size distribution. Results of a parametric analysis of cross-section versus incidence angle are presented for various rain conditions.

For an assessment of viewing angles used by scatterometers, a comparison is presented of backscattered power from stalks and ring-waves. A ring-wave model was derived from laboratory observations by Bliven et al. (*Int. J. Rem. Sens.* 1993, 14, 855-870 & 14, 2315-2329). Ring-waves originate from each drop-impact and propagate outward for several tens of centimeters. The comparison between the two models shows interesting results and it highlights the need for further experiments to refine models of rain-generated topographic features that contribute to microwave scattering from the sea-surface.

# ABOUT POSSIBILITY OIL-PRODUCTS DISCOVERING ON THE WATER SURFACE BY TWO-FREQUENCY METHOD AT THE MM-WAVE BAND.

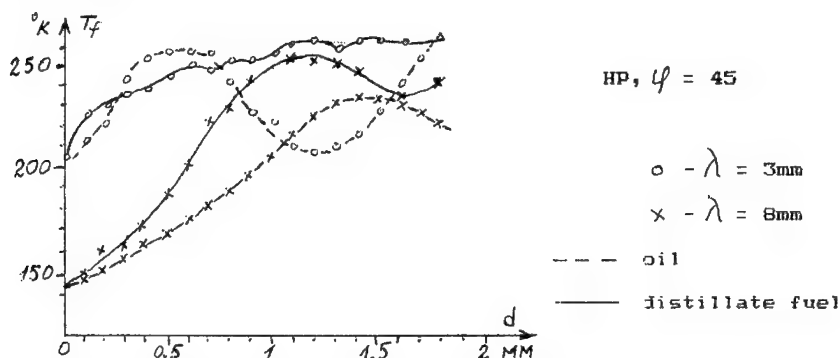
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This report presents results of experimental and theoretical investigation of radiating characteristics of some types petroleum-product films covering smooth water surface.

Radiometer measurements was made by means of two radiometers with 39 GHz and 94 GHz operation frequencies at the horizontal (HP) and vertical (VP) types of polarization. The fluctuation sensitivity of the radiometers  $\delta T < 0.15^\circ\text{K}$  (with  $\tau = 1\text{s}$ ), the angle resolution of antenna  $5^\circ$ .

Radio-brightness temperature of clean water surface  $T_c$ , radio-brightness temperature of covered with petroleum-product film water surface  $T_f$ , radio-brightness temperature of sky  $T_s$  measured in the mirror direction from angle sighting direction to the surface were measured in the experiments. The figure show typical experimental dependencies  $T_f$ -value of oil layer thickness ( $d$ ) which can be used to evaluate amount of oil slick contrast.



Besides that, the employment of the two-frequency polarization measurements and the flat layered medium radiation model offers to calculate the layer thickness  $d$  and complex permittivity of layer substance ( $\epsilon$ ). Such that, it is of prime importance the influence of measurement errors of  $T_o$  (thermodynamic water temperature),  $T_s$ ,  $T_f$  and error of setting the angle sighting ( $\varphi$ ) on the accuracy of  $d$  and  $\epsilon$  calculations. As the theoretical analysis shows,  $T_f$  and  $\varphi$  errors have a general influence on the accuracy of those calculations. The medium angles of sighting are optimum for minimization of the calculation errors.

The final part of report is devote to the description of the aircraft radiomapping system which is designed to practically evaluate the two-frequency remote sensing method.

## Measurement of Ocean Wave Properties Using a Vector Slope Gauge: An Error Analysis

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In November of 1990, the Synthetic Aperture radar and X-band Ocean Nonlinearities (SAXON-FPN) experiment took place in the North Sea off the coast of Germany. The University of Kansas participated in this experiment by operating a switched-beam 35-GHz radar vector slope gauge (VSG) that independently measured the ranges to three nearby points. From the ranges, we calculated two orthogonal components of the slope and three wave heights.

There are several potential sources of error when determining wave heights and slopes in this manner. Error in slope measurements can occur because the slope at a point is approximated by a plane formed by three points on the ocean wave. Phase information can be affected because the point of measurement moves along the radar beam rather than vertically. Slope and phase information can also be affected if there is a dominant scatterer at the perimeter of the radar footprint. In addition, if the angles used to locate the points of measurement are not accurate there will be an additional source of error.

Here, we present our method of determining ocean wave slopes and wave heights from three independent range measurements. In addition, we discuss several potential sources of error and propose modifications to correct for those errors.

## Model function development and testing of models for radar backscattering from the sea surface

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Fundamental knowledge about the intermediary physical processes which determine the radar backscatter from the ocean surface is at the moment still lacking. To improve the understanding of the interaction between microwaves and water waves in the framework of the VIERS (Dutch acronym for "Preparation and Interpretation of ERS-1 data") project two wind/wave tank experiments and an ocean tower experiment were conducted, while airborne scatterometer data became available through the participation in different ESA windscatterometer campaigns.

An important objective of the VIERS project is to develop and test a model for backscattering for the sea surface. Such a model consists of two main modules: one for the radar backscattering and one for the water waves.

The wave module of the VIERS model is based on a wave model of P. Janssen. In this model the energy balance of the gravity-capillary waves includes all relevant processes, viz. wind input, 3- and 4-wave interactions, viscous dissipation, wave breaking and quasi-linear effect. The gravity part of the wave spectrum is a Jonswap parameterization; the Jonswap parameters depend on wave age. In the wave module the assumption of a fully developed sea is dropped and a wave age dependent spectrum is calculated.

In the VIERS project four approximate backscatter solutions or -models- have been compared. The models are: a small perturbation model, a two-scale model, the full-wave model, developed by Bahar and the Integral Equation Model from Fung.

The first VIERS experiment, conducted in 1988 in the Delft wind-wave flume yielded data which were excellently suited for a verification of the radar backscatter models. For this purpose, one needs detailed knowledge of the water surface at which the scattering takes place, as well as good radar backscatter measurements. Both elements are available in the data set. A lot of attention was paid to the acquisition of high quality, detailed measurements of the water surface. Both, conventional and sophisticated new wave measurement devices were deployed. Among these are, high frequency wave wires, a laser slope gauge and the imaging slope gauge.

Two comparisons were made between model calculations and observed cross sections: the dependence on the incidence angle and the dependence of the friction velocity.

The conclusion with respect to the incidence dependence is, that of the models which were compared, the modified two-scale gives the best comparison with the data. All models considered predict equal upwind/downwind ratio's. In order to be able to predict accurate wind directions with the ERS-1, the upwind/downwind asymmetry will have to be added in an artificial way at the moment. In the VIERS model, this will be done by the addition of a correction based on the observations by the ERS-1 (empirical correction).

It is concluded from this comparison that the VIERS-1 algorithm is performing well, even compared to CMOD4. The added advantage of the VIERS-1 algorithm over CMOD4 is, however, that it is based on physics so that dependencies on sea state, slicks, etc., are automatically included.

AN ANALYSIS OF THE THEORETICAL,  $K_p$ , AND SAMPLE VALUES OF THE  
NORMALIZED STANDARD DEVIATION,  $K_p(s)$ , FOR THE ACTIVE MICROWAVE  
INSTRUMENT (AMI) ON EARTH RESOURCES SATELLITE-1 (ERS-1)

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The values for  $K_p$  for the AMI are properties of the radar design. Typical values that have been provided range from 0.04 to 0.06. It is possible to check these design values by means of computations for a sequence of backscatter values for the same antenna and incidence angle. The sample values of  $K_p(s)$  do not agree with the radar design values. They can vary from the design values to as much as 1.00. This difference between theory and measurement has important implications for the interpretation of the data. Possible reasons for this difference are suggested.

**Ice**

## **Use of Active-Passive Microwave Remote Sensing Methods of Ice Cover from Satellites for Navigation Support in the Arctic**

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A complex of radiophysical equipment, mounted on "Okean" satellite allows us to obtain radar (3.15cm) and passive microwave images (0.8cm) of the same area independently of light and weather conditions. These images are transmitted to the self-contained data reception centers and are widely used for navigation support in the Arctic. It is impossible to determine all necessary sea ice parameters from satellite radar images. That is why we began to study the possibilities of a combined use of radar and passive microwave images for estimating sea ice parameters and worked out the methods for their combined use and interpretation.

A radar image is basic in analysis because of a better spatial resolution. Such sea ice parameters as ice edge position, areas of predominant old ice, total ice concentration, leads and fractures in massifs of compact ice, flaw and shore leads, giant ice floes, ice drift can be retrieved from their analysis. Passive microwave images are used as complementary in the process of radar image decoding. Though the resolution of microwave radiometer is about 25 km, it distinguishes sea ice edge from wind roughened water, determines ice presence in large fractures and some other peculiarities of ice conditions more accurately.

Methods of digital image processing are used to compose ice charts from satellite images. Algorithms and programs have been worked out, which allow us to implement the interactive image processing in operating mode. Results of image processing are presented as digital ice charts in "Contour" format, which can be sent to users.

Ice drift vectors can be determined from a pair of successive radar images of the same area. Same ice floes are identified visually on both images and their geographical coordinates are determined. After that a procedure of interpolation for randomly distributed ice drift vectors to regular grid points is carried out. Composed ice charts can be used for the verification of ice forecast models and operating estimates of ice conditions variations for navigation.

The research on automated image interpretation is carried out. This research includes automated delineation of areas, calculation of ice concentration in delineated areas, recognition of the same objects on successive radar images (for ice drift determination).

Our experience on the use of "Okean" and "Almaz-1" images for sea ice monitoring and navigation support allow us to formulate the proposal for onboard facility of perspective satellites.

In our opinion, this complex should include SAR (wavelength 3-6cm), operating in two regimes. Signal processing in the first regime (swathwidth-500km, resolution-250-400m) should be carried out onboard the satellite. In the second regime (swathwidth-100 km, resolution-30-50m) signal processing is carried out at the Earth. The Control system of the satellite should change the beginning of swath. Both regime of current transmission and storage of data should be used. HRPT standard line (1.7Ghz) can be used for low resolution image transmission and 8.2 Ghz line—for high resolution regime. The regime, including combined work of SAR, scanning microwave radiometer and advanced visual scanner (MSU-M2) of low resolution should be implemented.

# CHANGES IN THE SURFACE PROPERTIES OF THE GREENLAND ICE SHEET FROM AN ANALYSIS OF SEASAT & GEOSAT ALTIMETER DATA

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Early indications of climate change in the polar regions can be detected by monitoring the surface properties of the polar ice sheets. Datasets provided by the Seasat and Geosat satellite altimeters cover large portions of Greenland and Antarctica. The time span between the operation of the Seasat satellite (1978) and the Geosat satellite (1985-1989) offers a unique opportunity to document changes in the ice sheets. Recent work has demonstrated that significant amounts of sub-surface volume scattering occurs over major portions of the ice sheets at altimeter frequencies. In previous work, we developed a model and algorithm that uses a combination of both surface and volume scattering (S/V) to describe altimeter return waveforms from the ice sheets (Davis and Moore, *J. of Glaciology*, 39, 133). The extinction coefficient of snow,  $k_e$ , is the geophysical parameter that describes the amount of sub-surface signal penetration. The extinction coefficient in turn is primarily related to the grain size of the near-surface ice crystals.

In the work presented here, we determined the mean value of the extinction coefficient along the ice divide of the Greenland ice sheet using data from the Seasat and Geosat altimeters. The mean value was obtained by fitting individual altimeter waveforms with the S/V model in 1 degree (long.) by 0.5 degree (lat.) areas and averaging all the extinction coefficients from the waveforms together. The result is shown in Figure 1 below. From the figure we see that in the lower latitudes the Seasat and Geosat extinction coefficients are very nearly the same, while in the higher latitudes the Seasat extinction coefficients exceed the Geosat values by as much as 100%. This indicates that the average grain size of the ice crystals in this region may have decreased during the time span between the two altimeter datasets. Two possible causes of this would be either a decrease in the mean annual temperature or an increase in the snow accumulation rate referenced to the 1978 values. Both of these possibilities are evaluated using additional ice-sheet observations reported by other investigators.

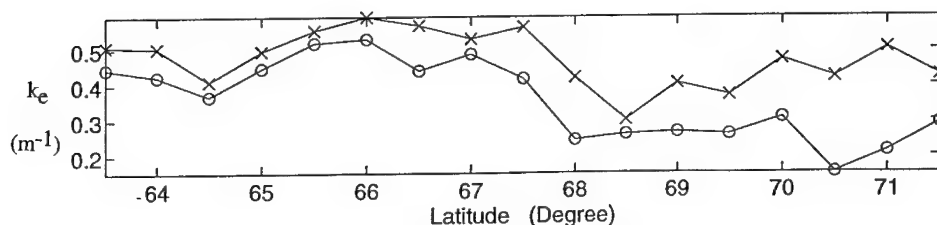


Figure 1. Mean value of the extinction coefficient of snow along the ice divide of the Greenland ice sheet from the Seasat (X's) and Geosat (O's) altimeter datasets.

C-Band Emission From Stratified Antarctic Firn:  
Comparing Models With Measurements

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Abstract

Microwave radiometry may allow the remote sensing of interesting geophysical quantities over the Greenland and Antarctic ice sheets. Fily and Benoist used SMMR data and found a statistical correlation between microwave emission and the accumulation rate inferred from ground station measurements (Fily and Benoist, *J. Glaciology*, 37, 129-139, 1991). Temperature profiles and snow accumulation rates are thus evidently linked to structural features of the firn which then affect emission. These findings provide motivation for a better understanding of how firn structure affects microwave emission. In this presentation, we study the effect of horizontal stratification of firn density on its microwave emission. A study performed by Rott in Antarctica supplied snow characterization data along with coincident ground-based radiometer observations at C-band and X-band (H. Rott et al, *Annals of Glac.*, 17, in press 1992). These data permitted a detailed statistical study on the effects of scattering from interfaces between horizontal density layers in the firn. We used a stochastic model to describe the layered structure of the firn. The parameters of the stochastic model were derived using an objective statistical procedure. To compute the emission from the stochastic model, we used a theoretical model based on fluctuation dissipation theory for a stratified medium. Results were then Monte Carlo averaged over an ensemble of realizations. The beam pattern of the radiometer is also accounted for in the calculation. The calculation uses all available ground truth data, and employs essentially no free parameters. At two of the sites measured by Rott, the model agrees well with the measurements. At a third site, the layered structure was too fine to be resolved by available ground truth measurements. Using subjectively derived parameters, however, the computed emission was still consistent with measured emission. If scattering from layers is neglected, the computed emission is higher than measured values, and the computed polarization contrast is smaller than the observed contrast. In conclusion, we find that scattering from layer interfaces plays a dominant role in determining C-band emission from dry Antarctic firn. Layer scattering reduces emission levels and increases the difference between horizontally and vertically polarized emission.

## **A Dynamic Local Thresholding Technique for Distinguishing Sea Ice Thicknesses in SAR Data<sup>1</sup>**

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### **ABSTRACT**

We present an approach to sea ice classification through a combination of methods, both algorithmic and heuristic. The resulting system is a comprehensive technique which uses dynamic local thresholding as a classification basis and then supplements that initial classification using heuristic geophysical knowledge organized in expert systems. The dynamic local thresholding method allows separation of the ice into thickness classes based upon local intensity distributions. Because it utilizes the data within each image, it can adapt to varying ice thickness intensities due to regional and seasonal changes and is not subject to limitations caused by using predefined parameters.

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<sup>1</sup>This work was funded in part by a NASA Graduate Student Fellowship in Global Change Research Fellowship, number NGT-30189, and by a NASA grant, number NAGW-3043.

USING GROUND TRUTH TO UNDERSTAND THE EFFECTS OF  
SUB-SURFACE FEATURES ON RADAR ALTIMETER RETURN  
WAVEFORMS FROM THE PERCOLATION ZONE IN GREENLAND

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AND

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In the summers of 1991 and 1993 NASA conducted airborne altimetry experiments to monitor the current status and recent changes in the surface altitude and topography of the Greenland ice sheet. In total, over the two summers, the NASA Wallops Flight Facility P-3 aircraft, equipped with the NASA Ku-band AAFE radar altimeter refurbished by the University of Massachusetts, the NASA AOL and ATLAS laser altimeters and several GPS receivers, flew twenty missions over the Greenland ice sheet.

Comparisons between AAFE radar altimeter and AOL laser altimeter altitude measurements over the different diagenetic zones of Greenland show that the AAFE is very sensitive to volume and sub-surface scattering. These results are especially prevalent in the percolation zone where melt water percolates down into the ice sheet and refreezes into ice layers, lenses and channels. In order to investigate the effects of these ice features on the AAFE return waveform, a ground truth experiment was conducted on the ice sheet at Dye 2 (66.48° N, 46.27° W) during the 1993 airborne experiment. A sample distribution of the ice layers, lenses and channels was obtained by probing a 5 x 5 meter area of the snow pack. Measurements of snow density, dielectric constant, temperature and crystal size were also acquired down to a depth of 2 meters at several sites around Dye 2. During the four week period of the experiment, the AAFE radar altimeter flew directly over the Dye 2 camp site five times, obtaining waveforms during several stages of the melt period.

A comparison between the return waveforms and the ground truth will be presented along with models illustrating how ice features affect the shape of the AAFE waveform. Knowledge of the relationship between the radar return waveform and the sub-surface scatterers allows prominent scatterers, such as ice layers, to be located in other areas of the ice sheet. It also enables mapping of transitions from the percolation zone to the wet and dry-snow zones.

## Microwave Backscatter From Laboratory-Grown Saline Ice

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As part of an ongoing set of experiments to better understand the microwave electromagnetic response of sea ice, we have made Ku-band radar and physical properties measurements of laboratory-grown saline ice at the U.S. Army Cold Regions Research and Engineering Laboratory. Our broad objective has been to identify the dominant microwave scattering mechanisms in order to be able to extract useful geophysical information about sea ice from remote sensing. We collected radar data at four linear polarizations and at various incidence angles for an ice sheet grown under controlled conditions in an indoor tank. The ice sheet was allowed to grow undisturbed and then was artificially roughened for purposes of studying the influence of rough surface scattering relative to volume scattering from air and brine inclusions. We measured linear profiles of surface roughness with comb gauges, and extracted roughness statistics after filtering and averaging. In addition, we monitored ice temperatures, thicknesses, and salinities. Results of our study are presented here, focusing on the roughness observed on both the undisturbed and artificially roughened ice, and the effect of this roughness on radar backscatter. Finally, using understanding gained from these experiments, we have simulated backscatter from young ice as it forms and grows, in an attempt to understand the relationship between radar backscatter and ice thickness.

# Observations of seasonal and interannual sea ice variations in the Barents and Kara seas through the use of SMMR and SSM/I data

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## Abstract

Monitoring of sea ice extent in the Barents and Kara seas is of importance for environmental studies as well as commercial use of these areas. Mapping the large seasonal and interannual variations of sea ice extent is used in climate studies and in planning future commercial projects. Sea ice concentrations are calculated using the Norwegian NORSEX algorithm on the Scanning Microwave Multichannel Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I) data sets. The NORSEX algorithm shows good consistency in the 1987 overlap period between the SMMR and SSM/I data sets, which thus provide a reliable record from 1978 to 1991. Statistical relations are used to characterize ice advance and retreat characteristics in the freezing and melting periods for the entire time span.

## **COMBINED USE OF RADAR AND MICROWAVE RADIOMETER IN REMOTE SENSING OF SNOW**

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The feasibility of remote sensing of snow by microwave radar and radiometer is investigated in a 4-year program. The main goals of the program are to determine the capability of radar and radiometer to map snow cover and the effect of forest canopies to snow mapping accuracy. Airborne scatterometer (5.4 and 9.8 GHz, 4 polarizations at each frequency) and microwave radiometer (24, 35, 48 and 94 GHz, vertical polarization) data along with ERS-1 SAR (5.3 GHz, VV polarization) images are used.

The test site is located in Sodankylä, northern Finland (center latitude = 67.41N, center longitude = 26.58E) and it consists of sparsely forested areas and open areas (bogs, lakes, and clear-cut areas). A total of 19 test lines have been selected in the Sodankylä test site. The test lines include various surface and vegetation types. The properties of forest canopies along the test lines have been measured, including tree type, height and timber volume.

A total of six airborne campaigns has been carried out in 1991-1993, including snow-free, dry snow and wet snow conditions. Results from airborne microwave measurements show that a radiometer can discriminate dry snow from other snow situations also in forested areas. Refrozen snow is detected best at 94 GHz. Based on scatterometer measurements, the highest values for the backscattering coefficient are obtained under dry snow conditions. The capability of radar to discriminate various snow situations is better at X-band than at C-band. Using ERS-1 SAR data, wet snow can be discriminated from dry snow and snow-free terrain. Combined use of radar and microwave radiometer data allows discrimination of dry snow, wet snow and snow-free terrain.

## STRUCTURE DEPENDENCE MODEL OF WET SNOW MICROWAVE EMISSIVITY FOR REMOTE SENSING

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Snow cover is one of the major elements of Earth cryosphere and is the most widespread natural cover of the Northern hemisphere in winter. Its state affects significantly hydrology of water basins, catastrophic phenomenon in mountains, crop capacity, etc. Therefore, the acquisition of accurate and timely information about the snow cover is of prime practical importance.

Passive microwave sensors have shown sensitivity to snowpack physical parameters, snow brightness temperature depend on snow stratigraphy. Determination of snow cover parameters through data of microwave remote sensing requires electrodynamic models of snow allowing one to compare its physical parameters and, in particular, snow stratigraphy, with its emissivity. In previous paper (D.A. Boyarskii et. al. JEWA, 7, 959-970, 1993) we have shown that two-flow model of dry snow emissivity agrees well for experimental results when snow stratigraphy, in particular size distribution of ice grains is included.

The primary purpose of this study is to derive a structure dependence model of microwave emissivity of land surface wet snow.

Presence of water in the snow cover considerably changes its physical properties and the character of processes taking place in it. For correct description of wet snow emissivity it is important to take into account the form of water inclusions as well as space distribution of water component in snow cover. We modeled wet snow either by the medium that contains spherical ice grains covered with the water shell (under low wetness of the snow), or by the medium that contains spherical ice grains and water drops (under the wetness  $> 4\%$ ). Two Flow Theory is applied. Absorption and extinction cross sections of individual scatterer calculated by the Mie theory.

To study the relation between the physical properties and brightness temperature of the snowpack, we have carried out a complex ground-based experiment during which the physical characteristics and  $T_B$  of wet snow were determined concurrently. Microwave radiometers, operating at 3.95, 19.5, 37.5 and 150 GHz and placed in a tower, were used for  $T_B$  snow measurements.

We calculated snow cover brightness temperature, taking into account the results of glaciological measurements of snow physical parameters as well as the results of structural parameters estimation of snow cover layers. Ice grains size distribution histogram in a snowpack layer we approximated by logarithmic-normal distribution with the statistical characteristics (average grain diameter and size variance) derived from the histograms.

The agreement of experimental and theoretical frequency dependencies of brightness temperature of wet snow takes place only if snow cover stratigraphy is taken into account.

**Oceans/Ice**

## *Effects of Multi-scale Roughness on Surface Scattering*

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### **Abstract**

It is well known that the sea is a rough surface with many scales of roughness and over large angles of incidence backscattering appears to be dominated by small scale roughness. These observations are intuitively plausible. In the literature interaction between large and small scales of roughness has been accounted for by averaging the small scale contribution over the slope distribution of the large scale roughness. This intuitive approach is also plausible but it is not clear how large should the large scale be relative to the small scale. It is also not clear whether this kind of tilting effect is the only important mechanism. For surfaces with two roughness scales generated by independent Gaussian processes, it is possible to have an analytic representation for both the correlation function and the surface spectrum. Thus, backscattering from individual roughness scales and total backscattering can be computed and the relative sizes can be changed to examine the impact of interaction between the two scales of roughness. For a two-dimensional surface we can also verify the backscattering results by moment method simulation. In this study, comparisons are made by changing relative sizes, and correlation functions. It is found that in general there can be significant interaction between roughness scales so that the idea of simple addition of contributions from two independent scales does not work. Furthermore, the total backscatter tends to have a scattering behavior similar to that exhibited by the small perturbation model (SPM). Thus, in general the SPM can generate predictions that can match total backscattering with effective surface parameters over the large incident angular region.

POLARIMETRIC MEASUREMENTS  
OF SEA SURFACE BRIGHTNESS TEMPERATURES  
USING AN AIRCRAFT K-BAND RADIOMETER

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This paper presents the first experimental evidence that the polarimetric brightness temperatures of sea surfaces are sensitive to ocean wind direction in the incidence angle range of 30 to 50 degrees. Our experimental data were collected by a K-band (19.35 GHz) polarimetric radiometer (WINDRAD) mounted on the NASA DC-8 aircraft. A set of aircraft radiometer flights was successfully completed in November 1993. We performed circle flights over NDBC moored buoys deployed off the northern California coast, which provided ocean wind measurements. The first WINDRAD flight was made on November 4, 1993. There was clear weather with a wind speed of 12 m/s at 330 degrees around the Pt. Arena buoy. We circled the buoy at three incidence angles, and all data when plotted as functions of azimuth angles show clear modulations of several degrees Kelvin. At 40 degrees incidence angle, there was a 5 degrees Kelvin peak-to-peak signal in the second Stokes parameter Q and the third Stokes parameter U. The Q data maximum is in the upwind direction and U has a 45 degrees phase shift in azimuth - as predicted by theory. There is also an up/downwind asymmetry of 2 degrees Kelvin in the Q data, and 1 degree Kelvin in the U data. The data collected at 50 degrees incidence angle show very similar wind direction signatures to the SSM/I model function. Additional flights were made on other days under cloudy conditions. Data taken at a wind speed of 8 m/s show that at 40 degrees incidence Q and U have a smaller azimuthal modulation of 3 degrees Kelvin, probably due to the lower wind speed. Additionally, the simultaneously recorded video images of sea surfaces suggest that Q and U data were less sensitive to clouds, breaking waves and whitecaps, while the  $T_v$  and  $T_h$  increased by a few degrees Kelvin when the radiometer beam crossed over clouds, or there was a sudden increase of whitecaps in the radiometer footprint. The results of our aircraft flights clearly indicate that passive polarimetric radiometry is a viable option in space remote sensing of ocean surface wind direction as well as wind speed.

ESTIMATION OF SURFACE WIND SPEED IN HURRICANES USING  
AIRBORNE MICROWAVE SPECTRAL RADIOMETER MEASUREMENTS

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Estimation of expected surface winds is a key component of hurricane warnings issued by the National Weather Service's National Hurricane Center (NHC) for coastal and marine interests. Until recently, no reliable means of measuring surface winds in hurricanes over the open ocean prior to its landfall has existed. This problem frequently leads to an over-estimate of surface winds at sea from aircraft flight level reconnaissance observations and consequently an overestimate of surface winds at landfall. Over warning comes at a tremendous price, since a preparedness cost of 50 million dollars per storm is incurred typically twice per year.

An airborne remote sensing method has been developed for estimating surface windspeed from reconnaissance aircraft. The technique employs a Stepped Frequency Microwave Radiometer (SFMR) mounted looking downward from the aircraft belly. The SFMR measures upwelling brightness temperature at five frequencies between 4.9 and 7.2 GHz. At these frequencies, the surface emissivity is directly correlated with surface wind speed through the area coverage and intensity of foam and whitecaps created by the surface stress and wave breaking. In addition, the attenuation of the surface emission is strongly dependent on frequency. These dependences allow estimation of the rain rate in the region between the aircraft and the surface and the surface windspeed. The technique will be presented along with several case studies.

## MODEL OF COMPLEX DIELECTRIC CONSTANT OF WET SNOW IN THE 1–50 GHZ RANGE

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The study of snow has become an important area of research in hydrology and climatology.

The increase in accuracy of land surface parameters retrieval from radiometer data requires the definition of snow dielectric behavior. Electrodynamically, a snow medium is, in general, a three–component dielectric mixture consisting of air, ice and water. The complex dielectric constant of the snow is a function of electromagnetic frequency, physical temperature, snow density, depth, free liquid water content, ice particle size and size variation. While dealing with dielectric properties of such a mixture we assume that the particle sizes of the components composing it are big enough to show its dielectric properties and simultaneously are small enough as compared to wavelength. This makes the using of quasi–static approximation possible.

A major objective of this study was to describe the wet snow permittivity at microwave frequencies as a function of its physical parameters. We introduced a way of taking into account the scattering by means of using dynamic polarizability of the spherical particles that compose the medium. We have been modeling wet snow by the air medium, containing spherical ice grains covered with water film and spherical water inclusion. The structure parameters of the ice particles and the space distribution of liquid water have been taken into account in our model.

We obtained the expression of the general formula that describes effective permittivity of dielectric mixtures consisting of two phases of spherical scatterers with different sizes and taking into account scattering losses. The prediction of the model agree well with the experimental data in the wide range of snow parameters. The distinctive feature of this model is the lack of free parameters and the use of real physical characteristics of snow.

POLAR ICE TEMPERATURE ESTIMATION FROM SATELLITE BORNE  
PASSIVE MICROWAVE MEASUREMENTS

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Knowledge of ice surface temperature in the polar regions is central to studies of hydrology and biology, as well as global climate models. In the Arctic this information has been inferred from data gathered by buoys drifting on ice floes. The considerable difficulties of this method have encouraged the remote sensing community to develop alternatives. Satellite based infrared sensors such as the Advanced Very High Resolution Radiometer (AVHRR) offer greater Arctic coverage and high spatial resolution, but information retrieval is seriously constrained by cloud cover contamination. Satellite based passive microwave instruments are more robust in this sense, but at the cost of ground spatial resolution.

Previously, ice temperature estimates have been derived from the Scanning Multi-channel Microwave Radiometer radiances. The SMMR temperature algorithm makes use of the first order relationship between brightness temperature and physical temperature (at 6.6 GHz vertical polarization). The algorithm also used total ice concentration estimates derived from the other SSMR channels via the NASA-Team algorithm. The NASA-Team algorithm was later modified and applied to data from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I). This was possible because most of the SSM/I channels are very close in frequency to the SSMR channels. The SSMR temperature algorithm could not be used, however, because SSM/I lacked the 4.6cm channel.

A modification to the SSM/I Team algorithm was developed to investigate the possibility of extracting a temperature product from the SSM/I passive microwave data. The operation of the algorithm will be explained, and several case studies will be presented. The derived temperatures will be evaluated with respect to estimates derived from buoy measurements and also clear scene temperatures derived from the AVHRR.

**VAGSAT: A PROPOSAL FOR A SMALL SATELLITE MISSION FOR  
THE MEASUREMENT OF OCEAN WAVE SPECTRA WITH A REAL-  
APERTURE RADAR**

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For several years, satellite programs for observing sea state have been developed. Satelliteborne radar altimeters now provide on a nearly operational basis the significant wave height. However, observation of the significant wave height without information of the wave spectrum may be insufficient to improve significantly the wave forecast models performances. Space-borne Synthetic Aperture Radars (SAR) such as those on Seasat, ERS-1, Almaz, Radarsat,... were developed, among several goals, for measuring directional wave spectra. It is however known that analyzing spectra of SAR images over the ocean in terms of wave spectra is quite complex, and that the non linear transfer function between the image spectrum and the wave spectrum filters out some wave components. Therefore, the possible configurations where SAR images alone can be inverted are considerably limited. This is the reason why we proposed, in response to the call for ideas of the french and european space agencies, a different radar system for the measurement of wave spectra from space. The proposed system is a Ku-band radar pointing to the surface with small incidence angles (around  $10^\circ$  relative to nadir), with a real aperture antenna, and scanning conically to cover the horizontal plane over  $360^\circ$  in azimuth. The validity of the measurement principle was demonstrated several times by means of airborne radars (Jackson et al, J.G.R, 90, C1, 1985, Hauser et al, IEEE/TGARS, vol 30 n5, 1992). It was shown (Jackson et al, Symposium "Measuring ocean waves from space", John Hopkins Tech. Digest, Vol 8, 1989) that the same principle could be applied to satellite measurements. Our proposal relies on these previous studies.

**ERS-1**

## ON THE USE OF ERS-1 SAR DATA FOR THE RETRIEVAL OF BARE SOIL GEO-PHYSICAL PARAMETERS

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In order to retrieve geo- and bio-physical parameters from microwave remote sensing data, a very detailed description of the interaction of the electromagnetic waves with the earth terrain being imaged is required. In the case of SAR images, both ground data and radar data are needed in order to validate direct models, i.e. predict the backscattering coefficient as a function of the soil parameters, and retrieval algorithms to derive bio- and geophysical parameters from the SAR data.

Taking advantage of the three-day repeat orbit of ERS-1 during the Phase D, SAR data (C-band and VV polarization) have been collected over a flat area in the Middle Zeeland in the Southern part of the Netherlands. At the same time, an intense ground campaign took place in which not only soil moisture measurement but also surface profiles, obtained by a laser-profiler, have been gathered. During the period of the campaign, the terrain was very uniform and mostly covered by bare soil surfaces.

Using the precise description of the rough surfaces obtained by the laser-profiler, a comparison of the results obtained by several theoretical models for surface backscattering is performed (e.g. geometrical optics, physical optics, small perturbation model, and the integral equation method) and their domain of validity for ERS-1 data is investigated. Furthermore, using these direct models, possible methods to invert SAR data in order to derive roughness parameters and soil moisture are discussed.

## **Improving Interpretations of ERS-1 SAR Images by Combination with Coincident AVHRR Images**

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The synergism of synoptic spaceborne synthetic aperture radar (SAR) and infrared radiometer (IR) remote sensing images improves understanding of radar imaging mechanisms and leads to more complete interpretations of geophysical processes in the marine environment. Two cases are examined; first, the sea surface temperature field derived from the NOAA AVHRR is compared with the sea surface roughness pattern derived from the ERS-1 SAR radar, and second, the structure of horizontal roll vortices in the atmospheric boundary layer derived from NOAA AVHRR is compared with the sea surface roughness pattern derived from ERS-1 SAR.

The first IR-SAR comparison (images obtained 6 hours apart) document a good qualitative agreement between the sea surface temperature and roughness field. The structure of the sea surface temperature field with the curvi-linear temperature fronts, represents mesoscale variability of 50 km scale characteristic of the unstable Norwegian Coastal Current. Smaller, 10 km scale features are also present. The ERS-1 SAR image contains frontal features with configuration and orientation in good agreement with those seen in the IR image, both at the 50 km and at 10 km scale. The agreement suggests the potential of SAR for providing quantitative information of mesoscale upper ocean circulation features.

The possibility to compare boundary layer cloud structure and surface roughness patterns is demonstrated in the second comparison. The NOAA AVHRR IR image and the SAR image were obtained about 20 minutes apart on 16 January 1992, off the ice edge along the East Greenland Current. The IR image depicts the cloud structure evolving downwind from the ice edge in the Greenland Sea associated with horizontal roll vortices in the atmospheric planetary boundary layer. A mean roll spacing of about 4-5 km is found near the ice edge, increasing downwind. The SAR image reveals the corresponding surface roughness in the open water just off the ice edge. The sea surface roughness pattern is streak-like with an orientation aligned in the direction of the roll vortices seen in the IR image and with a spacing between the streaks in agreement with the estimate from the IR image. The comparison suggests that submesoscale atmospheric boundary layer phenomena which induce a varying sea surface wind field, and hence wind stress, are detectable by the SAR. In some cases, moreover, quantitative estimate of the atmospheric boundary layer physics are also possible from the SAR images.

## **MESOSCALE ATMOSPHERIC PHENOMENA STUDIED BY ERS-1 SAR**

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Mesoscale atmospheric phenomena like atmospheric boundary rolls, convective cells, lee waves, Karman vortex streets, and catabatic wind fields are associated with variations of the sea surface roughness, which can be measured by the ERS-1 SAR. By using a C-band wind scatterometer model, image intensity variations detected in SAR images of the ocean can be converted into variations of the surface wind speed. From this estimates of atmospheric parameters associated with the underlying atmospheric processes can be obtained.

In this paper ERS-1 SAR images of the Jade Bay in the German Bight of the North Sea and over the Greenland Sea showing sea surface manifestations of atmospheric boundary layer rolls are presented, compared with in-situ measurements, and interpreted in terms of an atmospheric boundary layer model.

Furthermore, ERS-1 SAR images showing sea surface manifestations of the following atmospheric phenomena are presented and interpreted in terms of atmospheric models:

1. Convective cells generated by an unstable air-sea interface over the Mediterranean Sea.
2. Lee waves generated by a strong westward wind blowing over the Sierra del Haus mountain range in Morocco.
3. Karman vortex street generated by the interaction of the wind with the volcano of the Italian island of Stromboli.
4. Cold catabatic winds blowing at night from the mountains of Southern Italy and Sicily over the warm coastal waters of the Mediterranean Sea.

## ASSESSMENT OF ERS-1 SAR DATA FOR THE RETRIEVAL OF SOIL MOISTURE

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This paper presents an interpretation of ERS-1 SAR data acquired over several agricultural test-sites. The objective is to assess the use of ERS-1 SAR data for the retrieval of soil moisture.

Several experiments have been made in the past few years to determine the relationships between the radar backscatter responses derived from ERS-1 SAR data and the soil moisture content. It was observed that for bare soil or very sparse vegetation covered soils at many places, the radar backscatter coefficients were strongly related to the soil moisture content. However, the relationships may appear site and time dependent, due to the effect of the soil surface roughness.

Theoretical models are used to interpret the observations. For this purpose, past airborne and ground based multifrequency, multipolarisation data have been used to validate and intercompare selected rough surface models including small perturbation method, Kirchhoff approximation and integral equation method. The validated models are used to interpret ERS-1 SAR data and to define the conditions in soil surface roughness for which it is possible to derive soil moisture content from ERS-1 SAR data. Also, a discussion will be given on the use of additional frequency and polarisation for a more robust retrieval algorithm.

#### Calibration of the Active Microwave Instrument onboard ERS-1.

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The paper presents an overview of results with calibration of the SAR mode and the Scatterometer mode of the Active Microwave Instrument AMI onboard the ERS-1.

Almost three years of successful operation have led to a better understanding of calibration principles and enabled the comparison of calibration methods based on distributed targets and point targets. Calibration factors from the Amazonian rain forest (already mentioned as calibration target in the early days of radar remote sensing) give results, comparable to the extremely stable ESA transponders.

The long period of ERS-1 operation has also improved our insight in systems stability and atmospheric effects. The continued calibration program with the three ESA SAR transponders in The Netherlands (Flevoland) and three SCATT transponders in Spain proves to be of high value.

While 12 years ago, in Alpbach, a better-than-3-dB accuracy in radar was still questioned on serious grounds, the current status in radar calibration meets or even supersedes the better-than-1-dB accuracy that is considered vital to most applications.

## Observations of Temporal Changes in Crop Backscatter Using ERS-1 SAR

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Changes in crop size and height throughout the growing season will generally cause a corresponding change in the radar backscatter for the crop. These temporal changes will have different profiles depending on the crop being considered and may allow effective crop discrimination using a single frequency, single polarisation SAR such as ERS-1. In order to observe such changes it is critical that the radar be well calibrated (to <1 dB) and that full account be taken of variations caused by soil type, weather conditions and agricultural practices.

This paper presents the results obtained from measurements made using ERS-1 SAR over two growing seasons (1992, 1993). The principal crop studied was winter wheat, although other crops such as barley and sugar beet were also included. Four different sites were used in East Anglia, UK, each site having different soil characteristics and each containing large numbers of fields of the same crop. This allowed crop signature variability to be studied over a relatively large region. The SAR was calibrated by means of precision corner reflectors erected on sites close to the crop growing areas. These reflectors provided a cross section of 46.7 dB with a corresponding accuracy of  $\pm 0.3$  dB.

The results of the calibration work have shown that ERS-1 SAR can provide  $\sigma^0$  measurements to an accuracy of within 1 dB but that temporal variations in power were observed which may be confused with the temporal variations in crop signature.

The crop measurements show striking similarities over the two growing seasons, despite the differences in rainfall from year to year. However, there are differences in temporal profiles which need to be explained in terms of crop growth. Variations from field to field were also observed except that these variations tended to appear as a shift in bias rather than as a change in growth profile.

The results indicate that the prospect for crop discrimination from temporal backscatter profiles is good but that considerable care has to be taken to obtain well calibrated data.

## **Crop Discrimination Using Multi-Temporal ERS-1 SAR Data**

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A detailed study of temporal changes in the backscatter of agricultural crops has been undertaken as part of the UK ERS-1 SAR Calibration Experiment. This involved a programme of crop and soil measurements at four test sites with contrasting soil types/management practices in Eastern England, during the 1992 and 1993 growing seasons. In both years, calibrated ERS-1 backscatter measurements for more than 500 agricultural fields have been obtained from 10 ERS-1 precision images acquired during the 35 day cycle.

The analysis of temporal backscatter profiles for a variety of crops growing on different soil types indicates that backscatter is affected by crop type and development stage, and also by meteorological variables. However, the effect of crop development stage at critical periods in the growing season on backscatter is sufficiently strong to produce characteristic profiles for different crops. These differences are apparent even for crops growing on different soil types and under variable meteorological conditions.

A number of different techniques are tested for the classification of crop types based on these multi-temporal field backscatter measurements. Analysis of crop backscatter profiles is carried out to select optimum dates for crop separation. Crop classification results obtained for crops such as winter wheat and oilseed rape using 3 or 4 dates suggest that ERS-1 could have an important future role in the collection of agricultural statistics within Europe and in many other parts of the world.

## USE OF STATISTICAL ANALYSIS FOR ICE-OCEAN DISCRIMINATION

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### ABSTRACT

A statistical model and characterization of ocean SAR images acquired by ERS-1 satellite has been developed quite recently (Chapron, B., R. Garello and G. Engen, 1992. A Statistical Analysis of Sea State Surface ERS-1 SAR-Wave Mode Imagettes. *First ERS-1 Symposium : Early results*, Cannes, France, 4-6 Nov. 1992, pp. 739-742.).

We use a compound model based on the assumption of a multiplicative noise for the detected intensity,  $I = S \cdot Z$ . The fading noise  $Z$ , induced by the small scale variations is supposed to follow a Rayleigh law (Gamma law for multi-look images). The large scale variations  $S$ , modulating the return signal are distributed according to an unknown law. Nevertheless by analyzing the compound process statistics, different sea-states can be discriminated. For that purpose higher order statistics are used, namely third and fourth order (skewness ( $\beta_1$ ) and kurtosis ( $\beta_2$ )) are computed. Placing the ( $\beta_1$ ;  $\beta_2$ ) couple of points in the Pearson chart allows then to characterize and find the most suitable distribution for the image intensity (or amplitude in the case of ERS-1).

As it is shown in (Delignon, Y., R. Garello and A. Hillion, 1992. Parameterization of Sea-State from SAR Images. in *Proceedings of International Conference on Acoustics Speech and Signal Processing*, San Francisco, California, 23-26 March 1992, pp. III.29-III.32.), the points fall close to the type III line in the Pearson chart, characterizing a Gamma distribution for the image amplitude when analyzing ocean SAR images.

$$p(A) = \frac{A^{\alpha-1}}{\beta^\alpha \Gamma(\alpha)} \exp\left(-\frac{A}{\beta}\right)$$

Shape parameter  $\alpha$  of this distribution is then closely related to the sea-state roughness and gives information about the scene homogeneity.

When analyzing ocean-ice images the distribution is clearly shifted towards a Log-Normal line (included in the type IV distribution in the Pearson chart). The use of statistical tools as the ones described above is a fast and reliable mean for discriminating and identifying the ocean-ice interface.

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# **STATISTICAL ANALYSIS OF THE RELATION BETWEEN SAR AND RAR OCEAN WAVE IMAGES.**

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## **ABSTRACT**

Images of the ocean surface obtained by Real Aperture Radar (RAR) are simply a map of the radar cross-section per resolution cell, subject to ocean surface geometry (tilt effect). When dealing with Synthetic Aperture Radar (SAR), one must introduce the velocity of the surface relatively to the radar carrier (ERS-1 satellite, for instance). This velocity is not homogeneously distributed over the scene, but is dependent on the spatial distribution of the resolution cells. This phenomenon leads to the velocity bunching effect, namely an apparent concentration and spreading of scatterers in the SAR image, and explains why waves traveling in the azimuth direction are imaged.

The aim of this study is to extract directly from the SAR images relevant parameters such as orbital velocity dispersion of the long waves (a parameter of prime importance in the MTF, Modulation Transfer Function, inversion scheme)

A model of the relation between RAR and SAR images is given by :

$$I_{\text{SAR}}(x) = \int_x I_{\text{O}}(x') \delta(x' - x + d(x')) dx$$

where  $x = x' + d(x')$  reflects the mapping of a position  $x'$  in the RAR image into a position  $x$  in the SAR one and  $d(x)$  is a random variable normally distributed and centered.

One can show that the average number  $N(x)$  of roots of the above equation [ $x - x' = d(x')$ ] is directly related to the number of superimposed facets in the SAR image (B. Chapron, R. Garelo, V. Kerbaol and J.M. Lefevre, "Nonlinear theory of Ocean-SAR transformation and statistical analysis of ERS-1 SAR-Wave Mode images," Second ERS-1 Symposium, Hambourg, G., 11-15 Oct. 1993).

The two first moments of the random variable  $N(x)$  representing the relationship between RAR and SAR images are then calculated. We find that the average number of superimpositions ( $E[N(x)]$ ) is proportionnal to the slope shift standard deviation and the variance is directly related to the shift correlation function.

A spectral analysis involving the higher-order moments estimation (bispectrum) is actually investigated in order to generalize the statistical approach we have developed.

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## Comparison of shipborne radar measurements and ERS-1 SAR images of sea ice

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The sea ice cover affects the climate by modulating the heat exchange between ocean and atmosphere. Most of the changes in the Arctic sea ice cover occur during seasonal transitions. These seasonal transitions impact heat exchange and salinity balance in the upper ocean. The freeze-up season, in particular, is responsible for most of the new ice growth, which increases the sea ice extent and increases the salinity of the upper ocean on an annual basis. Sea ice goes through dramatic metamorphoses during the seasonal transition from summer melt to fall freeze-up, which causes changes in its radar signature. Understanding these changes is vital in understanding and monitoring sea ice and its effect on our climate.

Shipborne C-band radar measurements multiyear ice show an increase in backscatter of as much as 13 dB at 25° incidence angle during the initial stages of freeze-up. This is due primarily to enhanced volume scattering. Re-freezing of moisture on or near the surface is believed to be the cause of this enhanced volume scatter. Here we will examine this transition with C-band SAR images from the European Remote Sensing Satellite (ERS-1). These SAR images are studied in light of the shipborne radar measurements to determine the capability of monitoring the changes that occur during freeze-up. We will also examine the utility of shipborne radar measurements in interpretation of satellite SAR images.

ERS-1 Investigations of Southern Ocean Sea Ice Geophysics  
Using Scatterometer and SAR Images

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Restrictions on the coverage and operating times of synthetic aperture radar (SAR) receiving stations in Antarctica result in limited space-time coverage, thereby restricting applications in studies of sea-ice geophysics. A method for supplementing 100 x 100km synthetic aperture radar (SAR) scenes of ice conditions is proposed using the non-imaging Scatterometer (EScat) mode of the AMI on board ERS-1. This new method produces enhanced resolution C-band images from 500-km swath, gridded EScat data, and resulting images improve the nominal 50-km resolution to an enhanced resolution of 14km (see Long et al.). Weekly images of the entire Southern Ocean poleward of 55° S are generated at intervals throughout the 1992 austral winter, enabling monitoring of sea-ice processes around Antarctica. This is in contrast to 25-m resolution SAR images, which are only acquired during operation of the German and Japanese Antarctic receiving stations at Bernardo O'Higgins and Syowa. While AMI SAR image pairs provide detailed indications of the ice motion and sea-ice conditions on the 100-km scale, time-integrated, medium-scale resolution EScat images can be applied in mapping basin-scale dynamics of the ice cover. The EScat images essentially map the mean backscatter coefficient at 40° incidence, or the gradient in backscatter across the 20-60° incidence angle range.

ERS-1 AMI SAR and EScat images are presented for the Weddell Sea and analyzed in regions where surface measurements were made during the Winter Weddell Gyre Study in 1992. Results indicate that the EScat imaging technique complements and enhances lower frequency temporal and spatial ice coverage obtained by SAR. It does so by providing multiple incidence-angle C-band measurements, which more effectively discriminate ice-surface conditions. Shipborne C-band scatterometer data are used to illustrate local-scale radar scattering characteristics of the pack ice. These data are combined with ice property measurements to evaluate the accuracy and utility of combining ERS-1 scatterometer and SAR images in geophysical investigations of Southern Ocean Sea Ice. EScat images clearly indicate the nature of the Weddell Gyre circulation, and can be used together with SAR images to monitor the flux of old ice out of the Weddell Sea during the winter. Together these data indicate the main sources of ice production during the winter, and clarify relationships between the dynamic and thermodynamic components of sea-ice growth, advance and retreat around Antarctica.

REMOTE SENSING OF MOISTURE PATTERNS AROUND LAKES USING  
COMBINED ERS-1 AND JERS-1 RADAR BACKSCATTER DATA

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Currently, there is great interest in exploring the potential of remote sensing to monitor the ecology of wetlands. Since wetland regions are very sensitive to global climate change processes, their overall extent as well as their hydrological characteristics can be used as indicators of climate change. Imaging radar sensors are particularly well-suited to rapidly monitor large wetland communities both on an areal as well as on a temporal basis. Because of its all-weather capabilities with regard to distinguishing not only water from land but also wet soils from dry soils, spaceborne radar systems can be developed as powerful tools to monitor the spatial patterns of moisture around wetland water bodies, and thereby delineate areas that can be treated as hydrologically uniform.

Our present research explores the combined use of data from the imaging radar sensors located aboard the ERS-1 and the JERS-1 satellites to monitor moisture patterns around lakes. The SAR sensor aboard ERS-1 operates at 5.3 GHz (C-Band) on VV-polarization at 23 degree mean incidence angle and has a spatial resolution of 30 m, while the one aboard JERS-1 operates at 1.28 GHz (L-band) on HH-polarization at 35 degree mean incidence angle with a spatial resolution of 18 m. Various ground conditions consisting of land, vegetation and open water (lake) were generated. Moisture values for land were assigned as a function of distance from the lake as well as the elevation based on our prior study of Landsat TM and MSS images of wetlands. Existing radar backscatter models were used to compute the radar backscatter coefficients for each pixel for each of the above sensor systems. Speckle was also incorporated in the images based on the number of looks averaged for each sensor. The simulated radar images were used to "recreate" the ground conditions by first classifying open water, vegetation and bare soil. After bare soil regions were identified, existing inversion algorithms were used to obtain soil moisture information for comparison with the originally assumed moisture conditions. It appears that the combined use of ERS-1 and JERS-1 data shows promise in monitoring moisture patterns around lakes and other bodies of water.

## **Atmosphere**

COMPARISON OF EXPERIMENTAL MEASURED AND SIZE  
CALCULATED TO VERTICAL PROFILES ATMOSPHERE  
ABSORPTION IN 3-MM WAVE BAND

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In solving problems of remote sounding of the Earth's surface, radioastronomy and satellite communication a necessity to select a base model arises which ensures good correspondence of calculated and experimentally measured values of absorption of the atmosphere ( $\gamma$ ).

In the present work an experimental check of the accuracy of the known methods of high-altitude profiles calculation of cloudless atmosphere absorption was performed by the radiometric method at the frequency of 94 GHz.

To calculate the absorption factors of water vapour a method of engineering calculation was used (Zrazhevsky Yu.A. J. Radiotekhnika e Elektronika, 5, 951-957, 1976) which does not require registration of a large number of spectral lines. With calculation of absorption in oxygen the method described in (Zhevakin S.A., Naumov A.P. J. Izvestiya VUZov, Radiophysics, 3, 433-450, 1966) was used.

The experiments were done by a 94 GHz radiometer with a fluctuation sensitivity 0.2K located on the ground and in a MI-2 helicopter. The flights were performed in the Kharkov region and were accompanied by checking of meteorological data during making measurements. The air pressure and temperature were monitored directly at a height of making measurements, humidity was monitored on the ground. The  $\gamma$  value in this case determined in accordance with the method of angular altitude sections and was carried out by a measurement of the sky  $T_B$  in directions changed from  $30^\circ$  to  $75^\circ$  from the zenith.

A statistical analysis of the results of the investigations performed on the ground showed that the ratio of the calculated to measured values of complete absorption (with a level of significance 0.95) in the autumn-and-winter period is  $1 \pm 0.06$  times and in the summer period is  $0.98 \pm 0.08$  times. Comparison of the results of measurements of vertical profiles absorption obtained from helicopters (about 10-15 flight-days per season) and the calculated results showed that maximal differences of  $\gamma$  value are  $< 0.15$  dB and that they decrease (both absolutely and relatively) with rising of the atmosphere lower boundary. The last observation apparently is related to stability of meteorological parameters of atmosphere lower layers which are less stable than the upper layers.

It should be noted that the calculation accuracy of the  $\gamma$  value can be in a number of cases markedly increased by defining more exactly profiles of high-altitude distribution of the air  $T_0$  which were used.

Thus, as the result of this study, possibility of satisfactory description (for evaluation of astroclimate, remote sounding, communication) of high-altitude profiles of atmospheric absorption with the models we selected is quantitatively evaluated and supported.

**ESTIMATION OF THE RAIN SIGNAL  
IN PRESENCE OF LARGE SURFACE CLUTTER**

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**ABSTRACT**

An experiment to use SIR-C to test SAR measurement of rain echoes is planned for the first SIR-C mission. An imaging radar designed for surface observation is far from ideal for rain measurement, but no SAR designed for rain measurement is available.

The limitation to rain measurement of a surface-imaging synthetic-aperture radar (SAR) is the ground signal that is clutter when rain is the target. Here we upgrade our previous estimates (IGARSS'93) of the feasibility of precipitation measurement by a space-borne SAR. The previous signal-to-clutter ratio (SCR) calculations used a model due to Soofi that predated Seasat. Here we show calculations of SCR using the Seasat SASS and the ERS-1 CMOD4 models for X- and C-band ocean returns, respectively. The calculations with these models confirm the earlier conclusions; i.e., the surface clutter is too large for conventional rain retrieval algorithms to work, at least over the sea.

It is known that weak signals may be estimated in the presence of a large noise component by averaging many independent samples. Here we use this technique to obtain an estimate of the rain signal for a SAR in presence of surface clutter. The estimate of the rain echo is obtained by averaging  $N_c$  samples of clutter in a separate measurement and subtracting this clutter estimate from the combined estimate of signal plus clutter.

In estimating the clutter we assume that the surface echo is the same outside the rain area as it is within. Since this is not likely to be true for storms with rain striking the ocean, we propose to estimate the clutter in the rain volume itself by processing with the full synthetic aperture. Because of the narrow Doppler bandwidth used for the surface echo, interference due to the broadband rain echo should be minimal. The combined echo, however, is processed with a much shorter aperture to permit receiving the entire rain echo, since its bandwidth due to turbulence is relatively wide.

The number of samples required for successful estimation (within 10 - 20 %) for off-vertical angles of incidence appears to be prohibitively large with normal resolutions. However, by appropriately degrading the resolution in both range and azimuth, we can obtain the required number of samples.

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A 75-110 GHz radar/spectrometer for pollution monitoring

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A multisensor approach is being developed at the University of Texas at Arlington (UTA) to improve upon current capabilities in environmental monitoring. These sensors consist of an FT-IR for operation in the near to thermal infrared regions of the spectrum, a long-path UV (LPUV) system and an active/passive millimeter-wave instrument that will operate over the 75-110 GHz atmospheric window. The report will discuss various aspects of the multisensor approach including the motivation and plan of operation and will focus on describing the millimeter-wave instrument. This instrument, now in laboratory and field testing stages, operates in three modes, as a radar, as a radiometer and as an absorption spectrometer. In the latter two modes the instrument has a spectral resolution of 100 MHz over the entire 75-110 GHz. In these modes the instrument scans through the approximately 350 channels 10 channels at a time. In the radar mode operation is limited to a bandwidth of about 500 MHz around 94 GHz. This is due to the limited bandwidth of the pulsed power amplifier. The instrument utilizes very high (50 dB) gain antennas in order to achieve the necessary S/N with small transmitted power for absorption pathlengths in the few hundred meter range. A high gain reflector returns the signal to the instrument so that the measurement is absorption over a 2-way path. The front-end of the instrument uses quasi-optical processing to separate the band into 4 9-GHz segments with minimal loss and to keep the effective noise temperature of the instrument low.

Design and performance of the instrument will be discussed in this report.

## Polarimetric Dual-Frequency Millimeter-Wavelength Observations of Stratus Clouds and Rain

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The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts has developed a unique polarimetric Cloud Profiling Radar System (CPRS). CPRS consists of 33 GHz and 95 GHz radar subsystems which can transmit vertically or horizontally polarized pulses. Transmit polarization can be changed on a pulse-to-pulse basis. The 33 GHz subsystem uses two 100 kW coaxial magnetrons to achieve polarization agility. The 95 GHz subsystem uses a 1.5 kW Extended Interaction Klystron (EIK) amplifier and a network of latching isolators. Each subsystem has a two channel receiver that simultaneously measures the phase and amplitude of the vertically and horizontally polarized components of the backscattered signal. Both subsystems transmit and receive through a common aperture. A one-meter-diameter rexolite lens and a special dual-frequency feed generate collocated beams at each frequency. Cross-polarization isolation of the antenna and feed is better than 30 dB at both frequencies. The radar is mounted on a truck and is fully self-contained and portable. A built-in diesel generator can provide electrical power continuously for over a week before refueling.

During the summer of 1993, CPRS traveled to Lincoln, NE where it observed several large storm systems. Collocated dual-frequency measurements of reflectivity, linear depolarization ratio and vertical velocity are presented for one particular storm. A precipitating stratus layer was observed for several hours. Polarization and velocity data identify the melting layer. Reflectivity measurements at the two frequencies clearly show Mie scattering in both rain and in the ice cloud above. Figure 1 is a verticle profile through a precipitating region of the cloud. The rain below the cloud was being blown horizontally by a shear. Particle sorting is illustrated by the changing ratio of 33 GHz reflectivity to 95 GHz reflectivity. Doppler measurements also indicate where regions of large rain droplets are located. Independent estimates of average raindrop size are made from both fall velocity and dual-frequency reflectivity data.

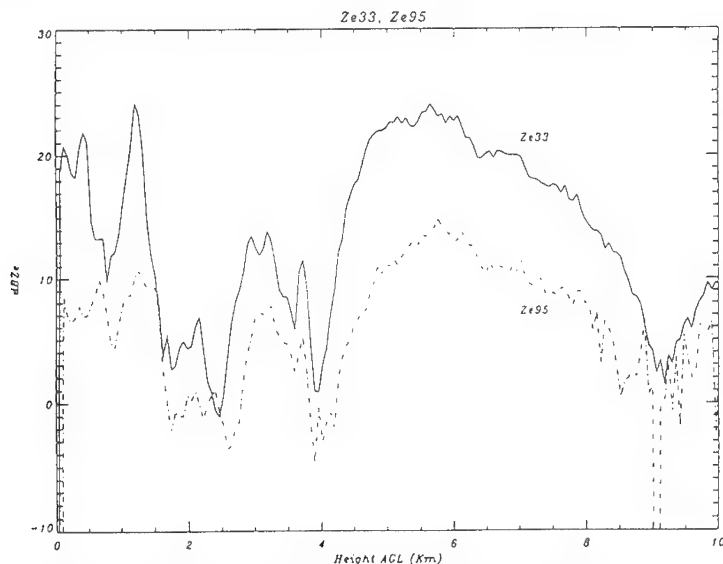


Figure 1: Verticle Profile of Ze at 33 GHz(solid) and 95 GHz(dash-dot).

**PRELIMINARY ANALYSIS OF THE PERFORMANCE OF THE SPECIAL  
SENSOR MICROWAVE WATER VAPOR PROFILER (SSM/T-2)  
IF SOME CHANNEL(S) BECOME(S) INOPERATIVE<sup>1</sup>**

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The SSM/T-2 instrument is a precision, five-channel, microwave radiometer. It has three channels near the 183.310-GHz water vapor resonance line ( $183\pm 1$  GHz,  $183\pm 3$  GHz,  $183\pm 7$  GHz), and two window channels (91 GHz and 150 GHz). The beams of the five channels have coincident centers. In a nominal orbit at an altitude of 833 km, brightness temperatures from the SSM/T-1 and SSM/T-2 instruments are used in the AFGWC's (Air Force Global Weather Center) weather prediction models. The SSM/T-2 ground processing software provides profiles of relative humidity, and absolute humidity, and water vapor mass at many pressure levels.

AFGWC noticed an anomaly in the weekend of 19-20 June 1993 in channel 5 of the SSM/T-2, serial number B-5 unit. The instrument has been in orbit on DMSP spacecraft F-11 since November 1991. It was incapable of measuring brightness temperatures from SSM/T-2 channel 5 ( $f = 150$  GHz). As a result, the operational SSM/T-2 ground processing software was idle. Aerojet proposed and compared two methods (Kieu, 1994) to resolve the channel-5 anomaly in the ground processing software. The first method involves the derivation of the empirical relationships between brightness temperatures of channel 5 and other SSM/T-2 channels. The second method suppresses information from channel 5 in the estimation of environmental parameters. With cooperation from Aerojet and Aerospace, AFGWC selected and implemented the first method to resolve the channel-5 anomaly.

This paper qualitatively evaluates the application of either method if other SSM/T-2 channel(s) become(s) inoperative. Channels 1 and 3 have been recently speculated to have abnormal characteristics. SSM/T-2 stratification algorithms need brightness temperatures of channels 1, 2, and 3 to correctly assign an atmospheric type to a profile of environmental parameters. The second method therefore seems inapplicable. The first method injects additional sources of errors in the estimation of environmental parameters. The implementation, complexity, and performance using the two methods in the retrievals of environmental parameters is also discussed in depth in this paper.

<sup>1</sup> The Department of the Air Force, Headquarters Space System Division (AFSC), Defense Meteorological Satellite Program partially supported this work under Contracts F04701-89-C-0036 (Production Contract) and F04701-92-C-0038 (Support Contract).

# SEASONAL-WEATHER INVESTIGATIONS EARTH COVER RADIATION IN 3-MM WAVE BAND

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To make a well-grounded choice of apparatus parameters of measuring systems of remote sensing and to workout and estimate algorithm efficiencies of their operation, it is necessary to get information on properties of radiothermal characteristics of various terrain surface types. At that, an experimental way of acquiring data of interest plays an important role.

In view of this, we conducted a cycle of experimental investigations of radiating properties and their season-weather stability of such terrain-surface types as sea, soils, vegetation, snow, asphalt-concrets cover were studied as well at the frequency of 94 GHz.

A considerable part of investigations was held under the accurately controlled conditions with the ground radiometer allocated on a tower with simultaneous measurements of the sky radiation state.

Figures 1 and 2 show, as an example, some of the typical functions of radiobrightness temperature ( $T_B$ ) which have been obtained at the work. The analogous series of season measurements by means of the helicopter radiometer permitted to make up more precise conclusions, applying them to real conditions, and to study the characteristics of surfaces with large size of special heterogeneity (coniferous and leaf forests, shrubbery and so on).

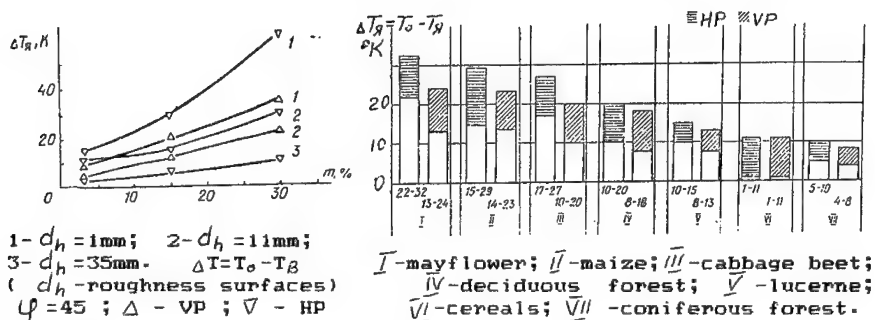


Fig.1 Moisture  $\Delta T$  - dependencies of open soils. Fig.2  $T_B$ -distinction of various vegetation types from  $T_o$  of surrounding air.

The obtained results presented in the report in the plotted form may be used for substantiating and choosing the apparatus parameters of the terrain remote sensing measuring radiometer systems on airspace carriers and also for designing and evaluating the efficiency of these systems operation algorithms.

**Vegetation/Soil**

EARTH SURFACES BACKSCATTERING CHARACTERISTICS  
IN 2-MM AND 3-MM WAVE BAND

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Practical applications of the short millimeter wavelength radar systems require knowledge of propagation peculiarities for these waves in the surrounding medium.

Therefore, the authors of this paper during a number of years realized a program of studying interrelations between biogeophysical parameters of different types of the terrain surfaces and characteristics of their backscattering within 94 GHz (for three polarization types - HH, VV, HV) and 136 GHz (for five polarization types - HH, VV, VH, CL, CR). The investigations were conducted using a sight towing angles 0-35° with respect to the nadir. Specific effective back-scattering area ( $\sigma^0$ ) were measured using the widely used method for comparing a signal received from the investigated surface with that from the reference reflector having the known  $\sigma^0$ . The analysis of the results obtained that the maximum dependence of the  $\sigma^0$  on moisture content ( $m$ ) for all the examined terrain is observed with the angles of view close to the nadir.

Moreover the highest sensitivity to the moisture-retention capacity (for its small and medium values) is observed at the cross polarizations, whereas for the magnitudes of  $m$  exceeding the medium values, it is observed at the copolarized component of terrain echo. Besides, we have noted a certain monotonic deflection in the dependence of  $\sigma^0(m)$ , which explanation is suggested in the report, and which seems to be a bit unexpected from the viewpoint of the widely spread theories.

Unfortunately, we failed to reveal reliable correlations between  $\sigma^0$  of the vegetation and such its parameters as the amount of the biomass, the height or the type of the crops etc. while analysing the results of measuring the reverse diffusion intensiveness of cereal crops and meadows in spite of the fact that the control over these parameters was carried out during the whole vegetation period.

Our measurements have demonstrated the absence of essential differences between  $\sigma^0$  values of different types of conformed polarizations. Even with quasi-smooth sand or asphalt surfaces they do not exceed 1.5 - 2.0 dB with visual angles 35° - 45° in short mm wave band.

As for the frequency dependence, for all cover types studied an insignificant rise of their  $\sigma^0$  (0.5 - 3.0 dB) is observed with the increase from 94 GHz to 136 GHz, except for cases when quasi-smooth asphalt and moistened ground surfaces were observed into the nadir. For them the reverse reaction was noted.

The revealed and quantitatively evaluated interrelations may serve as a basis for the development of methods of the Earth's remote sensing at the short-mm WB.

## **First Results from the European Microwave Signature Laboratory (EMSL)**

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Following the inauguration of EMSL in April 1992, the EMSL team received more than 40 experiment proposals from experts in the field of radar remote sensing. Based on these inputs the advisory committee to this large-scale facility recommended that priority should be given to themes which

- really require the unique features of the advanced facility EMSL,
- are technically relevant and currently of great interest,
- are in support of European projects for future air and spaceborne sensor design.

The suggestion for a list of priority is:

1. Interferometry
2. Radar imaging in a wider sense (including tomography)
3. Bistatic radar measurements
4. Analysis of radar wave penetration into material
5. Radar backscattering measurements

As a consequence the EMSL work concentrated primarily on experiments on interferometry and two- and three-dimensional radar imaging. The interferometric experiments relate to targets composed by simple point scatterers, multiple point scatterers, scattering areas and extended surface and volume scatterers. The work plan comprises a total of five experiments:

**SAR Imaging of Two Spheres:** This is a preliminary test to check the quality of phase patterns obtained from EMSL measurement data and to test the capability to obtain interferograms. Measurements are taken with two spheres as point scatterers, positioned on an absorber surface at different cross-range positions. The phase pattern of the data in the time as well as in the frequency domain will be evaluated.

**Tuneable Interferometry and Multibaseline Resolution Enhancement:** The goal is to evaluate the spectral shift of terrain reflectivity due to off-nadir angle variations. This spectral shift can be exploited to increase range resolution and therefore interferometric performances. Measurements are made for SAR imaging of an extended gravel surface with letter signs on it. Differences in the surface material (absorber or gravel as a distributed random scatterer) and in the signs' material (transparent / absorber / steel spheres as multiple point scatterers).

**InSAR Phase Error Estimation:** The accuracy in the extraction of topographic information from InSAR data is investigated by analysing the effects of random and controlled phase errors in the height estimation. Measurements are made for SAR imaging from a pair of corner reflectors and other elementary scatterers from different elevations with spatial arrangements over a gravel surface.

**Interpretation of Interferometric SAR Products:** Signal de-correlation, due to changes in soil samples (temperature, moisture, vegetation), will be investigated. Measurements are foreseen with different soil types, surface roughness variations and with vegetation cover.

**Effect of Soil Moisture on SAR Interferograms:** This test is aimed to evaluate the effect of temporal variations on soil moisture on the phase of the SAR images in order to explain some anomalies (moving fields) observed in interferograms from operational SAR. The results are not only promising but one could even state they are spectacular. The paper will provide a short overview on some of the results from imaging interferometric experiments.

## The Use of the Radar Equation for Truck-based Scatterometer Measurements from Vegetation

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Truck-based scatterometers are being increasingly utilized in controlled vegetation backscatter measurements. When comparing the scatterometer measurements with theoretical predictions, the procedure is two-fold: first one calculates the theoretical scattering coefficient, then one uses the latter to determine the received power via the radar equation. The question is, when is this procedure permissible?

To answer the above question, an analytic formulation of the problem has been developed. The formulation contains three key steps. In the first step, the scatterometer antenna beam is decomposed into plane waves. It is assumed that the canopy-air interface is in the far-field of the antenna. In the second step, the backscattering of each of these plane waves from a vegetation model is analyzed via the distorted Born approximation. Here, the vegetation is taken to be a layer consisting of a sparse random distribution of discrete scatterers over a dielectric half-space, and the antenna is assumed to be in the far-field of the scatterers. Finally, in the third step, the antenna reciprocity theorem is used to find the received voltage, and consequently the received power, in terms of the backscattered fields. The result is a very general expression for the received power.

Based on this general expression, we will present curves of simulation studies for the received power of a truck-based scatterometer. It is observed that when the ratio,  $r$ , of the antenna height above the canopy to the depth of the canopy becomes large, the results agree with the radar equation (and thus the use of the scattering coefficient). This has direct implications on the interpretation of truck-based scatterometer measurements from low  $r$  value configurations. A discussion of the subtleties involved will ensue.

## MODELISATION AND MEASUREMENT OF RADAR BACKSCATTERING OVER AGRICULTURAL BARE SOILS

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The capability of active microwave remote sensing technique is studied to retrieve soil moisture and soil roughness for hydrology applications.

The microwave backscattering over bare soils and its variation with the angle of incidence is both function of the dielectric constant and the spatial structure of the soil surface. To quantify the radar response, different electromagnetic models are used, the Physical Optic model over quasi periodic rough surface (R.T.Shin and J.A.Kong, *J. Appl. Phys.*,56(1)1657-1670,1984) and the Integral Electromagnetic Model (IEM) (A.K.Fung and K.S.Chen, *Int. J. Remote Sensing*, 13(9),1663-1680,1992). These models integrate the different spatial scales of the surface, represented by rows and clods. The IEM model integrate the spatial spectrum of the surface and have a large validity range. This last model is important because measurements of ground profiles parameters (length of correlation, height rms) show that with usual frequency bands (C and X bands), the radar data are out of classical validity range (PO and GO).

Our purpose is to compare simulations results with experimental radar database acquired with the airborne copolarized scatterometer ERASME (C and X bands) over the Orgeval watershed (France) during one year (1989) over various tillage practices (ploughs, sowing rows). Simultaneous description of the bidimensional soil structure has been acquired by moisture measurements and by heights profiles, parallel and perpendicular to the row/tillage structure.

First results show that in C band, the measured cross section variation with incidence angle (from 15 to 50 degree) remains flat, as expected over rough quasi periodic surface, but do not reproduce the simulated rapid angular decrease over smooth sowing fields. At shorter wavelength (X band), the data angular behaviour is well reproduced. It suggests that volume diffusion has to be modelised in long wavelength penetrating in the soil. Slight anisotropy of the radar response with view angle (parallel and perpendicular to the row direction) appears in measurements, but simulations predict it only for very smooth sowing structure.

## **GAS SENSING RADAR**

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For over forty years there have been reports of the radar detection of hydrocarbon gases seeping into the atmosphere from subsurface hydrocarbon accumulations. There reports have even stimulated a significant commercial activity in the conduct of hydrocarbon exploration surveys using radar. Such surveys are included in the broad range of measurement techniques termed geochemical exploration methods.

Despite the widespread investigation and even the use of this method for exploration, there has been little quantitative data reported that may be used to verify the existence of a unique radar return associated with the presence of hydrocarbon gases and more importantly to define the physical mechanism by which such a return might be generated. Most of the data gathered and the surveys conducted have utilized modified x-band marine radar systems with no provision for the measurement of absolute amplitude or frequency. Published data consists for the most part of screen reproductions of the standard marine radar PPI display. While no data has been published two patents have been filed on this technique, both describing the mechanism as one of "microwave fluorescence".

An instrumentation radar system was constructed capable of independent frequency variation of both transmitter and receiver over the x-band range. A measurement program was conducted using this system to investigate the existence of the reported anomalous radar returns and to provide quantified data by which some assessment of the physical mechanism giving rise to these returns might be made. The instrumentation system was operated in conjunction with the apparent industry standard marine radar system used to conduct exploration gas surveys (Raytheon Model 2700). The marine radar was used to locate areas agreed upon by experienced investigators to exhibit the anomalous return, then the instrumentation system was used to collect quantified measurements of these returns. In addition, measurements were conducted of captive volumes of propane, the hydrocarbon gas most often cited as the probable cause of the observed returns.

## A New Application of the Compact Range Antenna Concept to Geophysical Research

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<sup>3</sup> ElectroScience Laboratory, The Ohio State University

Radar systems used to measure the scattering properties of distributed targets generally utilize the far-field properties of antennas. But for smooth surfaces, reliance on far-field antennas complicates measurement of the scattering response near normal incidence because of the convolution of a relatively slowly varying, angular antenna response with a rapidly varying scattering pattern. This problem can be overcome by applying the compact range antenna concept. Here, a parabolic reflector with an offset feed effectively propagates a plane of constant phase over an area approximately equal to the diameter of the reflector and at ranges up to about twice the reflector diameter. This approach results in angular resolutions of less than a degree.

For the first time, this antenna concept has been used to study the scattering response of smooth and rough saline ice grown under laboratory conditions. By coupling the compact range antenna with a wide-band (2 to 18 GHz), network analyzer based radar, we have achieved exceptional definition of the near normal scattering response of the ice surface and subsurface. This approach is likely to have broad utility in a variety of other geophysical applications including studying the scattering response of the ocean, soils and vegetation.

In this paper, we briefly review the compact range antenna concept, describe the antennas so far developed, and discuss some of the results obtained during our saline ice experiments.

## **Systems/Calibration**

## Theory and Development of the Active Transponder for Altimetry Calibration (ATAC)

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25 January 1994

### ABSTRACT

The use of spaceborne chirped radar altimeters for measurements of ocean topography and mean sea level requires an unprecedented level of range bias calibration. Errors due to Electromagnetic Bias and other altimeter systematic biases are difficult to ascertain with external, independent measurement sources. It is highly desirable to utilize a calibration point in the altimeter data for determination of these error sources. Recent development of an Active Transponder for Altimetry Calibration (ATAC) promises a range bias calibration with a precision better than a few centimeters. Ephemeris constrained range rate compensation of the transponder return signal allows ATAC to target an *a priori* chosen altimeter range gate. Locating the ATAC return in the "toe" of the sea surface return minimizes its impact on the mean sea level track point and maximizes the signal-to-noise ratio. The use of a transponder for calibration of range bias error is ideal due to common mode rejection of atmospheric and orbit error sources. The development and operational theory of ATAC are discussed as well as current verification activities at the University of Colorado.

# A POLARIZATION SELECTIVE CORNER REFLECTOR FOR POLARIMETRIC SAR CALIBRATION

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To perform polarimetric calibration of an SAR, it is necessary to use three reference reflectors having different polarization characteristics. Polarimetric Active Radar Calibrators (PARCs) have sometimes been used to realize the specific polarization characteristics. However, PARCs have disadvantages of its relatively high price and the operation limitation only in a single frequency band.

Here we propose a polarization selective corner reflector (PSCR) as a reference target for polarimetric SAR calibration. The surfaces of the PSCR are made of a metal strip grating instead of a metal plate used in a usual corner reflector. For the design of a dihedral PSCR, a computation was made on the scattering characteristics of a metal strip grating as a function of the incident angle for several grating parameters. The reflection coefficients of a metal strip grating for parallel and perpendicular polarization at the incident angle of  $45^\circ$  were calculated to be 0.997 and  $2.70 \times 10^{-3}$ , respectively when both the strip and the gap widths are 10% of the wavelength. Therefore, the ratio of the RCS for parallel and perpendicular polarization, i.e. polarization discrimination ratio (PDR), is expected to be -51.4dB for a dihedral PSCR.

A prototype PSCR was manufactured for 5.3 GHz frequency band by putting a copper tape of 3 mm width on two surfaces of a Styrofoam cube with 3 mm interval to form a dihedral as shown in Figure 1. The measured RCS at 5.3 GHz of the PSCR for a parallel polarization was 25.61 dBm<sup>2</sup>, which is 1.12 dB smaller than the theoretical RCS value of a dihadral of the same dimension, while that for a perpendicular polarization was -19.33 dBm<sup>2</sup>. Thus the PDR was -44.94 dB of the present prototype PSCR. The smaller PDR and RCS in the experiment would partly be due to the error in the manufacturing of the experimental model. Figure 2 shows the measured backscattering characteristics of the PSCR for parallel and perpendicular polarization as a function of the incident angle. The result shows a possibility to use the PSCR for polarimetric calibration. Extension to a trihedral is now under way. The PSCR will be used in our SIR-C polarimetric calibration experiment to be carried out in the Sarobetsu test site in Japan.

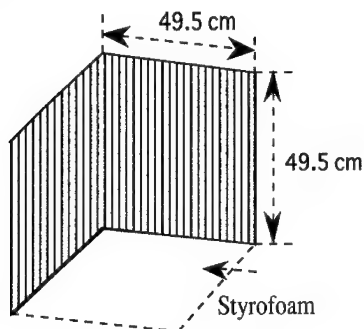


Figure 1. Outview of a PSCR.

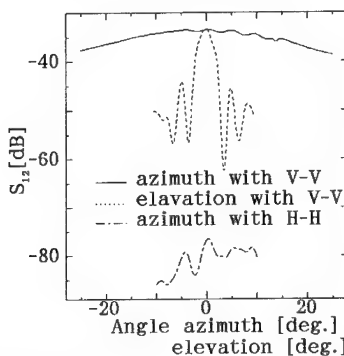


Figure 2. Backscattering characteristics of a PSCR.

THE JPL AIRCRAFT TOPOGRAPHIC SYNTHETIC APERTURE  
RADAR (TOPSAR) PROGRAM

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During the last few years, JPL has developed a C-band (6cm wavelength) aircraft radar system that acquires interferometric maps of the earth. This is an adjunct to the NASA/JPL Aircraft Synthetic Aperture Radar (AIRSAR) system that acquires multi-polarization SAR images at P-band (70cm wavelength), at L-band (25cm wavelength) and at C-band. The TOPSAR/AIRSAR system routinely flies on the DC-8 Airborne Laboratory operated by the NASA Ames Research Center. This TOPSAR/AIRSAR system operates such that the C-band interferometry can be acquired simultaneously with the P-band and L-band polarimetric data.

The TOPSAR system is implemented via two antennas mounted nearly vertically on the left side of the aircraft with a 2.6 meter baseline spacing. Interferometric maps of the surface are constructed by comparing the phase differences between SAR images from the two antennas. Statistical elevation errors for the TOPSAR system range from 1.0 meters for flat land to 3.0 meters for mountainous areas. Typical data acquisitions are for areas of 10 km across-track (i.e. in range) and up to 50 km along track (i.e. in azimuth). However a recent, summer 1993, observations in the Galapagos Islands (Islas Fernandina and Isabella) demonstrated that these 10 km-by-50 km topographic maps could be mosaicked together for an area of about 50km-by-50km.

During the summer of 1993, we experimented with "repeat pass" interferometry in an attempt to acquire phase-coherent SAR images from two separate, but nearly identical, aircraft flight paths. During 1994, we expect to improve the TOPSAR aircraft radar system by using a much better GPS/INS unit, which will enable mosaiking via dead reckoning. These aircraft observations are a precursor for a possible earth-orbiting TOPgraphic SATellite (TOPSAT), which is currently in premission studies at JPL.

## Scattering prediction and measurement of thin wire arrays with random heights

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Electromagnetic scattering models are used to derive information from radar data of remotely sensed objects. Theoretical model development is based on exactly solving scattering problems introducing approximations in order to be of practical use.

In this paper a simple model geometry is taken consisting of a linear array of parallel thin finite length electrically perfect conducting straight wires, or needles, with variable heights. The electric field integral equation (EFIE) formulation of the scattering from such arrays is solved with the Method of Moments (MOM). The calculations are verified by in-door anechoic chamber measurement of the mono-static radar cross section of a combination of two parallel needles in function of their mutual distance. Bi-static scatter calculation and measurement results of arrays of 16 and 128 needles with averaging over 32 arrays with randomly chosen heights are presented.

The wire scatterers are taken thin enough to allow for the approximation that the incident (plane) wave induces currents along the wire axes. The wires are discretized in segments. The impedance matrix of the wire array network is obtained by applying a current source to each port in turn and calculating the circuit voltages at all ports. After matrix inversion the port currents (the wire's current distribution) are obtained from the voltage excitation (the applied field) by simple matrix multiplication. Once the currents are known calculation of the scattered field is straightforward.

The number of segments used in the calculations is 8 for which results differ less than 0.1 dB compared to the 16 segment case. Other parameter values are: array width  $a=128$  mm, the needle height settings are random Gaussian and discretized on the experimental 1 mm resolution height grid and standard deviation  $s=9$  mm.

The measured results agree well with the calculated ones, be it that they are slightly higher in the 128 needle case, which is attributed to experimental mounting difficulty for such a large number of needles.

The needle diameter is 0.5 mm and the length is taken equal to the used radar wavelength of 3 cm for which the radar cross section can be accurately determined. Absolute calibration of the measurement results is based on the measurement of a single isolated needle suspended from a nylon wire of 0.1 mm diameter hanging vertically down, at the measurement spot. This is compared with the result obtained when the measurement is repeated with the needle placed in the center of the foam block that is used in mounting the several needle arrays.

## **Analysis of the 2-D Response Pattern of the EMSL Antennae and Applicability of a Polarimetric Calibration**

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The polarimetric calibration which is normally applied to microwave scattering measurements in anechoic chambers is rigorously valid only at the calibration point, where the reference target is placed. The correction to take in account for the range propagation loss can be easily implemented. On the contrary, the effects due to the antenna pattern modulation (in amplitude and phase) in azimuth and elevation are difficult to be compensated especially if the limited antenna cross-polarisation purity must be considered.

At the European Microwave Signature Laboratory (EMSL) the frequency band 2-18 GHz is covered by one transmit and several receiving antennae of the same type (dual-polarised wideband horn antennae) arranged in a quasi-monostatic and multistatic measurement configuration. In the frame of the performances assessment of the laboratory, a systematic investigation has been carried out to characterise the response of this antenna system in the area (diameter 6m) around the calibration point. A metallic sphere has been used as probe over a regular grid of test points.

This paper concerns the quasi-monostatic case where a polarimetric calibration can be implemented. If no correction for the limited antennae cross-polarisation purity is included in the calibration, a residual cross-polar term is present in the measured scattering matrix of the probing sphere (typically 20 dB below the co-polar response). If such a correction is applied the residual term is reduced by a factor which gives directly an estimation of the calibration effectiveness.

An improvement of 20-30 dB can be easily achieved in a narrow region (frequency dependent) along the antenna boresight. However, when the test point is moved away in azimuth and/or elevation, the correction does not work so well and becomes completely unefficient for large off-boresight angles.

The scope of this work is to assess the limits of the polarimetric calibration in relation to the characteristics of the antenna pattern (in azimuth and elevation) in order to derive practical criteria of applicability and to investigate possible alternative calibration strategies less sensitive to the antenna pattern distortions.

## PASSIVE MICROWAVE REMOTE SENSING WITH THINNED ARRAY RADIOMETERS

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The University of Massachusetts in cooperation with the Goddard Space Flight Center and the USDA Agricultural Research Service in Beltsville, Maryland have been working together to develop the technique of aperture synthesis (thinned array radiometers) for remote sensing from space at the long wavelength end of the microwave spectrum. Passive microwave remote sensing at long wavelengths offers the potential for measuring parameters such as soil moisture and ocean salinity which are needed for understanding the dynamics of the earth's environment. However, these long wavelengths require large antennas to achieve high spatial resolution, and the problems associated with deploying large antennas on satellites are sufficiently severe to have limited the utility of such passive microwave sensors in space.

A possible means of resolving this limitation is to use an interferometric technique called aperture synthesis to reduce the physical antenna aperture needed in space. In aperture synthesis, the coherent product (correlation) of the output voltage from pairs of antennas is measured at many different baselines. Each baseline produces a sample point in the two dimensional Fourier transform of the scene and a map of the scene is obtained by inverting the transform. The advantage of aperture synthesis for microwave remote sensing applications is that high spatial resolution can be achieved with sparse arrays which require no mechanical scanning. Sparse arrays are possible because only one measurement is needed at each baseline, and mechanical scanning is not needed because the image reconstruction algorithm yields a map of the entire field-of-view of the individual antennas. One obtains an instrument with a wide field-of-view by using pairs of small antennas in the interferometer.

As part of this research program, an aircraft prototype called ESTAR has been built. ESTAR is an L-band radiometer designed for the remote sensing of soil moisture. Initial flights near Goddard's Wallops Flight Facility in Virginia demonstrated that images could be successfully obtained; and recently the remote sensing capability of the instrument has been demonstrated in a series of soil moisture measuring experiments at the USDA watersheds at Walnut Gulch, Arizona (August, 1991) at the Little Washita River basin near Chickasha, Oklahoma (June, 1992). The instrument is currently undergoing changes to improve internal calibration and thermal control, and is scheduled to participate in another series of flights at the Little Washita River watershed in April (1994).

## Current status of the PHARUS (polarimetric phased array airborne C-band SAR) project

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**Abstract** - The definition study PHARUS was started in the first half of 1988 and ended early 1991. Three preparatory studies were carried out in the definition phase including the actual realization of a single-polarization C-band phased array research SAR (PHARS). The completion of the studies was rewarded with a successful testflight of the PHARS system on 8 November 1990.

In 1991 the realization phase of the project was started with a detailed design of the system. The system will be installed on a Cessna Citation II aircraft. The system will have a number of user selectable modes for polarizations (one to fully polarimetric), resolution (4 meter / 4 looks to 16 meter / 20 looks), altitude (5 km to 12 km), swath width (4.4 km, high resolution, polarimetric until 20 km, low resolution, one polarization) and incidence angle range. The different features within a mode are more or less coupled due to signal to noise limitations and maximum data rate. The radar is set up in such a way that extensions in a later stage are possible. For example a larger bandwidth or the enlargement of the antenna including the number of T/R modules is possible.

The system needs to be well calibrated. For systems using passive antennas the calibration problem may be divided in two parts: the external calibration taking care of the antenna pattern, including the antenna gain and polarization cross-talk whereas the amplitude and phase relations in the transmitter-receiver chain are calibrated using an internal loop. In the case of the PHARUS system, both calibrations will mix and the normal internal calibration in particular will become a fiction. Active antennas like this can only be calibrated when they are operational i.e. when all transmitter and receiver modules are active. In general two options can be considered to be appropriate for the calibration of active antennas: the use of a homogeneous distributed target, of which the scatter coefficient is known or the use of a point target of known cross-section in combination with antenna pattern measurements for all operational modes and a monitoring of the amplitude and phase behavior of all T/R modules. The outcome of this book-keeping must be incorporated in the SAR processing. In the PHARUS project the last option was chosen to be implemented in the system design.

It is expected that the system will be ready for its first testflight early 1995. After validation of the system, operational use will be possible mid 1995. The setup of the system is comparable with future spaceborne systems, especially the use of an electronically steerable phased array makes the system a good candidate as demonstrator for ESA's ASAR developments.

This paper will give an overview of the results of the definition phase including the results obtained from flights of the research SAR. It will discuss the PHARUS design, the different calibration aspects in the case of a polarimetric SAR system and the implications for the system design and will conclude with a discussion of the expected operational use and use as ASAR demonstrator.

## Opportunities for Combined GPS Orbit Determination and Spread Spectrum Altimetry

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### ABSTRACT

The availability of the Global Positioning System (GPS) and the possibility of utilizing spread spectrum ranging techniques can be combined into a system that offers important opportunities for an innovative remote sensing system which is applicable to both spaceborne and airborne missions. Of particular interest are spaceborne altimeter applications. The current state-of-the-art in satellite altimeters is that being flown aboard the TOPEX /POSEIDON spacecraft. Launched in 1992, this altimeter utilizes dual  $K_u$  and C band ranging to calibrate the delay effects of the ionospheric electron columnar content at the nadir. The inclusion of the C band ranging capability, with its associated mass and power requirements, results in a substantial added mission cost (approximately 50 %). The proposed new altimeter system will exploit on-board GPS tracking for orbit determination. The GPS derived radial orbit component allows the satellite altitude to be known in real time and is used to control the spread spectrum altimeter's transmit / receive (Tx/Rx) cycle. With a self-controlled method of Tx/Rx cycle, this altimeter becomes generic and will be capable of operating on many spaceborne or airborne platforms and at any altitude. For spaceborne ocean altimetry missions, the use of pseudo random noise direct sequence modulation will enable a single frequency ionospheric calibration mode. Combined GPS and spread spectrum altimetry provides optimized coherent detection and will eliminate the need for a cross correlation search algorithm. The estimated precision of this new altimetry data-type is comparable to the TOPEX for oceanographic mesoscale features and will also make contributions to global sea level measurements. Future altimetric remote sensing missions will likely favor the use of small, low cost satellites (i.e. Lightsat, spacecraft mass < 200 kg). This proposed combined GPS / spread spectrum altimeter will satisfy these Lightsat critical design constraints.

## Poster Abstracts

## **An Investigation into the Utility of High-Resolution Plane-Wave Scatterometer Measurements for Remote Sensing of Vegetation**

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When an electromagnetic wave is incident upon a vegetation canopy many complex interactions take place. In general, vegetation canopies consist of many components such as leaves, stems and trunks. Thus, a vegetation canopy is a volume scatterer because the scattering coefficient depends on the contribution of many of the canopy components. This situation complicates the problem of extracting parameters such as soil moisture and leaf area index (LAI) because the relationship between the radar signature and these parameters is not mathematically simple. In the past, three factors have limited our success in determining the interactions between the vegetation canopy and the electromagnetic waves. First, our current ground-based scatterometers do not have the resolution required to differentiate the return from different canopy components. Second, we have typically taken measurements at a given frequency with a relatively narrow bandwidth. This creates problems because at a given frequency the radar is not sensitive to certain parameters. For example, at X band the transmit signal may not penetrate to the soil layer. Therefore, the return would not be sensitive to soil moisture or surface roughness. Finally, the antennas used in our current scatterometer systems create a spherical wavefront rather than a planar wavefront. This causes our return at a given range to be dependent upon many different components of the vegetation canopy.

To resolve these problems, an ultra-wideband step-frequency scatterometer with a plane wave antenna was developed as a joint project between RSL and the Ohio State University's Electroscience Laboratory and Byrd Polar Research Center. The PLANARSCAT system operates from .5 to 12 GHz and includes a large offset parabolic reflector antenna used to create plane waves as long as our target range is no more than twice the diameter of the reflector. This is an idea developed originally for use in measuring antenna patterns in a compact range.

The high resolution of the PLANARSCAT allows us to determine what components of the canopy are dominating the return over a given band. This system will be tested in the Spring of 1994 over three different types of vegetation canopies. These include bare soil, a burned vegetation canopy and an unburned vegetation canopy.

This paper will include an explanation of the PLANARSCAT system and the DSP involved in recovering the scattering coefficients as a function of frequency. The paper will also present the preliminary results from the measurements taken during the Spring of 1994.

**Neural Network Based Classification of SAR Scenes  
Using Spectral Information: An Empirical Study**

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**ABSTRACT**

The use of a feed-forward artificial neural network (FANN) in classifying scenes from a SAR image, acquired over the FIFE KUREX test sites, is presented. Three different types of scenes such as river, forest, and grass-field are located on the SAR image with the aid of an optical image and a ground map. For each type of scene, one-hundred segments are located where each segment consists of 16x16 pixels. The texture information of each segment of the image is obtained by computing the spectrum of its intensity distribution, after removing the mean intensity from the individual pixel intensities. A feature vector is then obtained for each segment using 64 samples of the spectrum and the mean value of the intensity distribution of the image-segment. Ten different feature vectors from each type or class of scenes are used to train a feed-forward ANN, and the performance of the network is tested using the feature vectors that are not used during the training process. Different types of network architectures are considered in search of achieving optimal performance, and the results are compared with the classical Bayes classifier. It is found that a properly trained FANN provides superior performance in classifying three different types of SAR scenes than that of the Bayes classifier.

## **Preliminary Results from the Winter Weddell Sea Ice Classifications of ERS-1 SAR Imagery Using Neural Network**

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The Synthetic Aperture Radar (SAR) on board ERS-1 satellite, launched in July 1991, has provided the first ever C-band microwave radar images over the Southern Ocean. These images were used in conjunction with C-band field scatterometer data to investigate the applicability of neural networks in sea-ice classification problems.

In 1992, a C-band, ship-based scatterometer was mounted on board the German icebreaker *F.S. Polarstern* for the Winter Weddell Gyre Study. This FM-CW radar instrument was used to measure backscatter from sea-ice in the Weddell Sea during the months of June, July and August 1992. These are the first microwave scatterometer data ever to be collected in the Antarctic sea-ice cover during the austral winter. Backscatter measurements were made of several different types of ice at varying incidence angles, as *Polarstern* traveled from east to west across the central Weddell Sea. At each radar measurement location, in situ measurements were made of snow and sea-ice. Many of the stations were chosen to coincide with periods of near-simultaneous or coincident imaging by the ERS-1 SAR. This provided a valuable tool for interpretation of satellite SAR imagery from Antarctic sea-ice in terms of the impact of physical properties of sea ice and snow upon microwave backscatter signatures.

We computed the tonal and textural measures of various features that were identified within a SAR image. Next, the above features were uniquely classified using the in situ ice observation and accompanying AVHRR satellite imagery received in real time aboard the polarstern. Finally, an artificial neural network is trained, using the features, to classify different types of ice. In this paper, we present the results of the neural-network-based sea-ice classification of ERS-1 SAR images.

## A New Application of the Compact Range Antenna Concept to Geophysical Research

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Radar systems used to measure the scattering properties of distributed targets generally utilize the far-field properties of antennas. But for smooth surfaces, reliance on far-field antennas complicates measurement of the scattering response near normal incidence because of the convolution of a relatively slowly varying, angular antenna response with a rapidly varying scattering pattern. This problem can be overcome by applying the compact range antenna concept. Here, a parabolic reflector with an offset feed effectively propagates a plane of constant phase over an area approximately equal to the diameter of the reflector and at ranges up to about twice the reflector diameter. This approach results in angular resolutions of less than a degree.

For the first time, this antenna concept has been used to study the scattering response of smooth and rough saline ice grown under laboratory conditions. By coupling the compact range antenna with a wide-band (2 to 18 GHz), network analyzer based radar, we have achieved exceptional definition of the near normal scattering response of the ice surface and subsurface. This approach is likely to have broad utility in a variety of other geophysical applications including studying the scattering response of the ocean, soils and vegetation.

In this paper, we briefly review the compact range antenna concept, describe the antennas so far developed, and discuss some of the results obtained during our saline ice experiments.